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GEOLOGY OF THE HAYSTACK STOCK, COWLES, PARK COUNTY, MONTANA

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INTRODUCTION

The Haystack stock is a mass of coarse-grained gabbro, diorite, and allied rocks, situated at the head of Boulder River, near Cowles Post-Office, Park County, Montana, in the southeastern quarter of the Livingston quadrangle, about 65 miles by stage from Livingston. The geology of this portion of the Livingston quadrangle was mapped in 1890 by Professor J. P. Iddings, but the Haystack stock, and its relations to the surrounding rocks, were regarded by him as of sufficient interest to warrant further study, and, accordingly, in 1903, additional field-work was done by the writer, assisted by Robert Butler, A. C. Ellsworth, and James Walker. No claim for originality is made for the geological map, Fig. 1, since it is essentially that published in the Livingston folio. Mr. Iddings further directed the office work, and placed in the hands of the writer his field notes and a large amount of material collected during the mapping of the Livingston quadrangle. Analyses of six type specimens, and of two mineral separations were made in the laboratory of the U. S. Geological Survey by Mr. George H. Steiger.

PHYSIOGRAPHY

Topography.—The area included within the limits of the map, (Fig. 1), is a part of the high dissected plateau which is somewhat indefinitely called the Snowy Mountains. The general elevation of

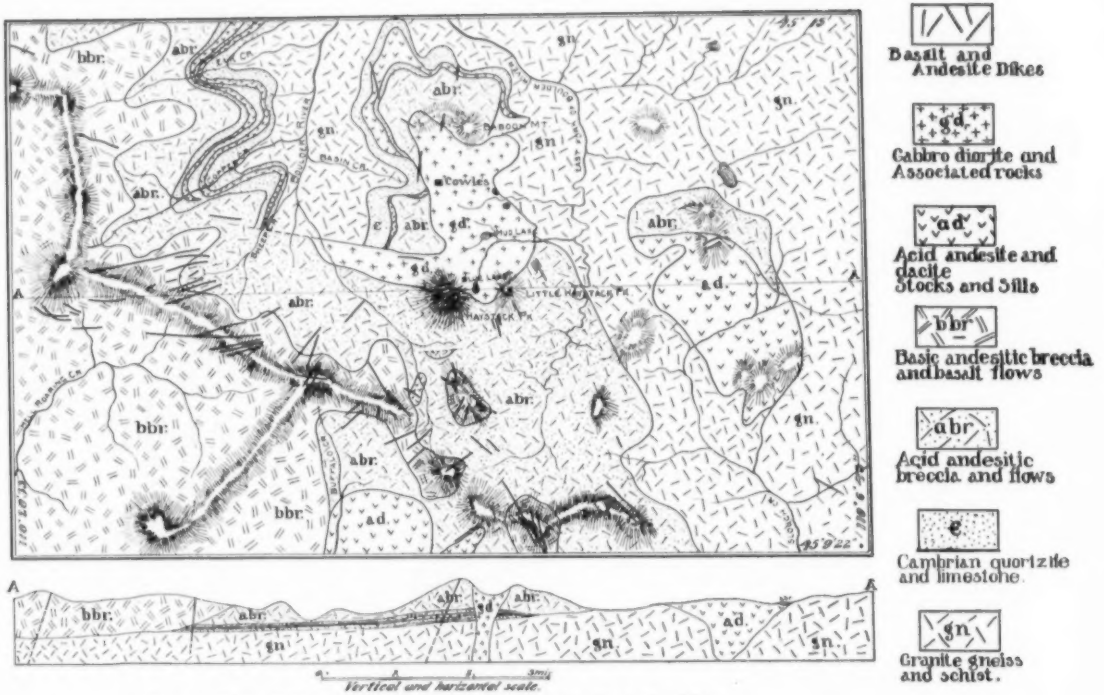

FIG. 1.—Map of Haystack stock and vicinity, Cowles, Park Co., Mont.

this plateau is from 9,000 to 10,000 feet above sea level and numerous peaks are higher. Of these the most conspicuous are Haystack Peak, Little Haystack Peak, and Baboon Mountain. Many canyons traverse the plateau and are sunk from 2,000 to 3,000 feet below the level of the upland. They are narrow, U-shaped, and their walls are very steep, even to the sources of the streams. The trees are mainly spruce, white bark pine, and lodge-pole pine. They are comparatively small and are valuable only for local use in connection with the nearly dormant mining industry. Aspens and willows grow in the marshes along the streams, and above 9,500 feet the vegetation consists chiefly of small junipers and stunted cedars.

Drainage.—The Boulder River is the most important stream of the area; rising south of Haystack Mountain it flows northward through the Snowy Range and enters the Livingston River at Bigtimber. Several tributaries join the Boulder River from the west, among which are Elk Creek, Copper Creek, and Sheep Creek. From the east its affluents are East Fork and Basin Creek. The southeastern portion of the area mapped is drained by Slough Creek which, flowing southward, joins the Yellowstone River in the Yellowstone National Park. Haystack Basin lies between Haystack Peak and Baboon Mountain. A low ridge, trending north and south, forms a watershed west of which the drainage is through Basin Creek into the Boulder River.

Effect of character of rocks upon topography.—The stock of Haystack Basin, especially the coarse-grained central portion, weathers very readily, falling into coarse arkose and consequently forms a relatively low area. The eruptive rock around the stock is very resistant, since it has been indurated at the contact and it forms the mountain crests to the north and to the south of the basin. Elsewhere, the breccia and minor intrusives appear to have been eroded at about equal rates. Dikes seldom stand out conspicuously above the surface, and other intrusives, aside from the Haystack stock, do not find marked expression in the topography. Sedimentary rocks have only a small areal distribution. They are nearly flat and do not form notable physiographic features. They outcrop only on the sides of the canyons and are represented by a quartzite member which usually forms a bench, above which is a ledge of limestone.

The differences in the constitution of the crystalline schists are too slight to find expression in topographic form.

Glaciation.—The effects of glacial erosion are conspicuous in the Snowy Mountains. The streams head in typical glacial amphitheaters, sharp and clear cut. On the floors of these amphitheaters in rock basins are occasional lakes. In this part of the valleys drift is thin or absent and at many places the rocks are polished or striated. Lower down in the mountains, usually three or four miles below the sources of the streams, the floors of the canyons are covered with drift which at many places occurs as knobs or hillocks from ten to forty feet high. Lakes and kettles within the morainal belt are comparatively rare.

Culture.—In some years a five-stamp mill is operated at Cowles Post-Office during a part of the summer and a number of prospectors do assessment work. As soon as the snow becomes too deep for easy travel, the country is almost deserted until the following spring. A wagon road connects Livingston with Cowles. From there trails lead southeast to Cook City and to the mines around Horseshoe Mountain. In the early 90's this area was the scene of considerable mining excitement, and a camp of a hundred or more houses, known as Independence, was built at the junction of Basin Creek and Boulder River. A mill was installed at this point and ore was hauled by wagon from the Independence mine in Haystack Basin. The camp was soon deserted, but the name is sometimes used for the camp at Cowles Post-Office, about a mile east of the old camp.

OUTLINE OF GENERAL GEOLOGY

Pre-Cambrian gneisses and schists.—The oldest rocks within this area form a crystalline complex consisting in the main of crenulated and intensely folded granite-gneiss and mica-schist. The gneiss is at most places coarse-grained, though medium or fine-grained facies are common. The gneiss is composed of feldspar, quartz, biotite, and muscovite, with hornblende and magnetite as accessory minerals. Like minerals are arranged in laminae giving the gneiss its banded appearance.

Traversing the gneiss in all directions are streaks of dark mica-schists varying in width from less than an inch to more than fifty

feet. The direction of schistosity agrees closely with the banding of the gneiss, and both were apparently produced at the same time. The dark schists consist essentially of biotite, feldspar, and hornblende. The contacts between the gneiss and the included schists are not sharp and distinct, though a short distance away they appear to be so, owing to the contrast in color between the light and dark rock. The two merge into each other within a narrow zone, and the bands of schist thin out and end within the gneiss. The forms assumed by the bands of schist are extremely irregular; some of them are curved lines; sigmoidal forms are not uncommon; rectilinear bands do not occur for any considerable distance. Some of the curved bands are fractured and broken by faults which have been completely healed.

Pegmatite.—The crystalline complex is cut by dikes of pegmatite which is composed of feldspar, quartz, and mica. Such dikes are especially well developed on Lake Plateau about two miles north of the northeast corner of the area mapped (Fig. 1) where red feldspars occur in large crystals which inclose smaller bodies of quartz, most of them about two inches in longest dimension, and thick six-sided plates of mica about half as large. The pegmatite is not mashed and, therefore, is later than the metamorphism of the gneiss and schist, but since it does not cut the Cambrian sediments it is probably of pre-Cambrian age.

CAMBRIAN

Overlying the pre-Cambrian rocks unconformably are beds of Cambrian quartzite, limestone, and shale. The basal member is a buff, pink, or gray quartzite from 200′ to 300′ thick, and its basal layers at some places contain small pebbles of the crystalline schists. The quartzite is thoroughly indurated, and under the microscope shows characteristic secondary enlargements of the grains of quartz.

Above the quartzite and conformable with it in dip is blue or gray limestone from 50′ to 300′ thick, near the base of which are a few feet of shale. It is sometimes massive, more often thinly bedded, and contains cherty layers. Some of the layers of the limestone are limestone conglomerate, composed of flat limestone pebbles from

one-half inch to five inches in diameter, cemented by a limestone matrix. The limestone has been extensively recrystallized since it was deposited and is largely composed of closely interlocking anhedrons of calcite, 1 mm or less in longest diameter. In some localities it is rich in fossils. On the trail about two miles northwest of the point where Boulder River is intersected by the northern boundary of the area mapped on Fig. 1, exposures show that certain beds of the limestone are composed almost entirely of fragments of trilobites. The quartzite is the Flathead quartzite of Mr. Weed[1] and the limestone is very probably to be correlated with the Meagher limestone in his section at Helena.[2]

Immediately south of Copper Creek, at a point about three-quarters of a mile above its junction with the Boulder River, the limestone, here thinly bedded and shaly, rests upon gneiss, showing that it was deposited by overlap upon the sinking Cambrian sea bottom.

The Cambrian beds dip gently west-southwest away from the pre-Cambrian rocks and are intruded by sills of andesite-dacite, and cut by the Haystack stock. At the contact with the stock the limestone is metamorphosed and locally contains secondary quartz, epidote, garnet, and an undetermined amphibole. The attitude of the Cambrian beds at the contact with the Haystack stock is approximately the same as away from it.

EXTRUSIVE ROCKS

Occurrence and distribution.—Overlying the crystalline schists and the sedimentary rocks and conforming to the irregularities of their eroded surface is a great thickness of extrusive rocks, consisting of breccias, tuffs, agglomerates, and lava flows. These rocks are formed of material thrown out of volcanic vents and are more or less continuous for many miles to the south and west, covering a vast area in and around the Yellowstone National Park.

The extrusive rocks do not represent a continuous series, for unconformities of erosion occur at many places. The presence of silicified trunks and stumps of trees, some of them upright as they grew, shows that between the volcanic eruptions there were periods of

[1] *Livingston Folio*, Geological Atlas of the U. S., U. S. Geological Survey.

[2] *Helena Folio*, Geological Atlas of the U. S., U. S. Geological Survey.

quiescence of considerable duration. At some of these unconformities there is an abrupt change in the appearance of the breccia. There are more or less constant differences between the lower and the upper portions of the breccia, and the series has been divided by Mr. Iddings[1] into the acid andesitic and the basic andesitic breccia.

The acid andesitic breccia.—The acid andesitic breccia consists chiefly of light-colored andesite, dacite, and latite fragments which vary in size from fine dust to masses several feet in longest dimensions. The coarse material is most abundant in the lower portion of the formation, while the upper portion contains beds which are composed almost entirely of volcanic dust. The chaotic basal portion contains large fragments of gneiss and quartzite, which were broken from the pre-Cambrian and Cambrian formations, and probably represent material thrown out at the time of the earliest eruptions. Such fragments are very abundant in the west wall of the Boulder Canyon due west of Haystack Peak.

The upper portion of the acid breccia is largely composed of fine material; some of it is well stratified but probably of subaerial origin. The bedded tuffs dip at low angles but the dip is not quaquaversal with respect to the Haystack stock. It is probable that the material from these beds came from several sources, and since much of it is very fine, the sources may have been a considerable distance away. The thickness of the lower acid breccia is variable and reaches a maximum of 1,500 feet. It is well exposed above the Cambrian on the divides between the tributaries of the Boulder River at the head-waters of this stream, also south of Haystack Peak at the head of East Fork, and at the head of the drainage of Buffalo Creek. There is an isolated remnant of the breccia capping the gneiss about two miles northeast of Little Haystack Peak. The acid breccia probably once covered a much more extensive area than it does now, and has since been eroded. Mr. Arnold Hague[2] has shown that in the Yellowstone National Park this early acid breccia belongs to the Eocene period and corresponds with the Fort Union horizon. The early acid breccia is cut by andesite-dacite stocks and

[1] Iddings, *Livingston Folio*, p. 6.

[2] "The Age of the Igneous Rocks of the Yellowstone National Park," *American Journal of Science*, Fourth Ser., 1896, p. 450.

by the Haystack stock. At its contacts with the Haystack stock the breccia is greatly indurated and weathers at some places like a massive rock. On account of its greater hardness this contact at most places forms a ridge. Since the border facies of the Haystack stock is fine-grained, it is impossible at many places to locate precisely the contact, though the doubtful zone is usually not more than a few yards wide.

Basic andesitic breccia.—The basic andesitic breccia is darker than the acid breccia. Chocolate, dark grays, and somber shades of red and yellow predominate. It is composed of pyroxene-andesite and hornblende-pyroxene-andesite, with a subordinate amount of dacite and latite. Fragments of gneiss or of quartzite are much less abundant than in the lower breccia. The fragments are generally smaller than those in the basal portion of the acid breccia and beds of fine-grained tuff are less conspicuous than in the acid breccia. Basaltic lava flows which are very common, especially near the top of the formation, are best developed in the southwest portion of the area. The thickness of the upper breccia is very great. The canyon of Hell Roaring Creek, several miles southwest of the area mapped, is nearly 3,000 feet deep and is cut entirely in this formation. It is probable that this breccia also was formerly more extensive and it may have completely covered the acid breccia. The basic breccia is of Neocene age.[1]

ANDESITE-DACITE INTRUSIVES

Andesite-dacite sills.—Andesite-dacite sills occur as sheets injected between the Cambrian strata. In this area they are present wherever a section of Cambrian rocks is exposed. At most places there is a sheet between the quartzite and the limestone at the horizon of the shales which occur at the base of the limestone and several sheets are intercalated within the limestone. The cartographic representation is necessarily generalized, showing from one to three of these sheets, but where the Cambrian beds are thickest there are sometimes more. The maximum thickness of the sills is about two hundred feet.

The andesite-dacite is dark gray, reddish gray, or brown, and contains phenocrysts of feldspar, hornblende, quartz, and biotite.

[1] J. P. Iddings, Folio 30, "Yellowstone National Park," Geological Atlas of U. S., U. S. Geological Survey.

Under the microscope the groundmass is seen to be microcrystalline and contains phenocrysts of andesine, green hornblende, quartz, orthoclase, magnetite, and biotite. Calcite and serpentine are present as secondary minerals. Orthoclase and quartz are sometimes present in considerable amount when the composition of the rock approaches that of quartz-monzonite-porphyry. Since the sills are cut by the Haystack stock they are older than it, and since they do not cut the breccias they are possibly older than them, and presumably the oldest Tertiary volcanics in the district.

Andesite-dacite stocks.—Andesite-dacite stocks cut the pre-Cambrian rocks and the basic breccia. The largest one is about two miles east of Little Haystack Peak, and covers an area of nearly two square miles. Several smaller bodies occur along the southern border of the area mapped.

The andesite-dacite is gray or pinkish gray, and contains phenocrysts of feldspar, hornblende, quartz, and mica. Under the microscope the groundmass is seen to be microcrystalline and contains phenocrysts of andesine, quartz, green hornblende, pyroxene, orthoclase, and magnetite. The andesite-dacite stocks are younger than the early breccia and probably older than the later breccia. They are closely allied to the sills in composition, but if the sills are older than the early breccia, which the stocks cut, a considerable period intervened between the two intrusions. The composition of the andesite-dacite is near that of the early breccia, and the sills, stocks, and breccia probably came from the same or closely related magmas.

The Haystack stock.—The Haystack stock is an intrusive body of irregular shape cutting through pre-Cambrian schists, Cambrian sedimentary rocks, and the early acid breccia. It is composed entirely of granitic rocks varying in composition from quartz-monzonite to olivine-gabbro. These grade into one another, and it is assumed that they represent the products of differentiation from a common magma.

Basalt and andesite dikes.—Basalt or andesite dikes cut all the other rocks. They are most abundant in the country south, west, and east of the Haystack stock, and have a rudely radial arrangement around it. In width they vary from four inches to forty feet and some are exposed for considerable distances, though most of them

are partially concealed by detrital material. In appearance the dike rocks are dark and either aphanitic or contain inconspicuous phenocrysts of augite, feldspar, and olivine. Under the microscope they show a considerable range of composition. The basalt dikes have a microcrystalline groundmass containing a large number of lath-shaped labradorite crystals which flow around larger phenocrysts of augite and olivine. Hornblende phenocrysts are present in some thin sections. In the less basic dikes, the andesites, the groundmass, sometimes glassy, contains a smaller amount of plagioclase and augite. Hornblende is more abundant than in the basalt dikes. Some thin sections show numerous large andesine phenocrysts. Some of the dikes can be traced into the Haystack stock, though none of them crosses it. Probably many of them are connected with it in depth.

PETROGRAPHY OF HAYSTACK STOCK

Relation to other rocks.—The Haystack stock occupies the greater part of Haystack Basin, extending eastward nearly to the East Fork of the Boulder River. A long arm trends westward from Haystack Peak for nearly a mile and crosses the West Fork of the Boulder River; another arm extends northwest to the western spur of Baboon Mountain. Its outcrop altogether occupies an area of about two and one-half square miles. The stock cuts through the crystalline schists, the Cambrian sedimentary rocks with intruding sills, and the early acid breccia. There is no evidence that the Cambrian beds were turned up by the intrusion, for wherever they outcrop near the stock, their attitude is approximately uniform and they dip southwestward at low angles near the stock in the same manner as at some distance away from it.

The western arm of the stock is closely related to a fault which extends westward from the north spur of Haystack Peak and crosses the Boulder River at an elevation of about 7,900 feet. North of the fault the Cambrian sediments occur some 600 feet above the stream bed on both sides of the Boulder River. South of the fault the Cambrian is wanting and the breccia is the lowest formation exposed. The minimum throw of the fault at this point is 600 feet. So far as known, the Haystack magma did not penetrate the shaly beds between

the Cambrian quartzite and the limestone. The sills in the Cambrian are characteristic of this formation over wide areas and are not to be regarded as apophyses of the Haystack stock; further, they are more siliceous in composition than the average of the stock, and they are thicker away from the stock than near it.

There is no conclusive evidence that the Haystack stock ever reached the surface. It is of later age than the acid breccia, and appears to have extended to near the top of this formation, but it may have been deeply buried under the basic breccia, which has a thickness of 2,000 feet or more in Hell Roaring Creek near by. Since, however, its composition is near that of the basic breccia, it is possible that it formed a channel through which a portion of this breccia reached the surface.

Appearance.—The peripheral facies of the Haystack stock is dark, fine-grained, and contains a few inconspicuous anhedra of feldspar and biotite. A short distance toward the center from the periphery, it becomes of lighter color and coarse grain, and is composed of feldspar, quartz, hornblende, and mica. Still farther from the border, it becomes much more coarsely crystalline, of darker color, and is composed of biotite, pyroxene, and magnetite. In the more basic facies of the central portion of the stock the ferro-magnesian minerals approximately equal the light-colored constituents. The various facies grade one into the other except in rare cases where locally there is a rather sharp contact between them. A notable example occurs near the wagon road a few rods south of the divide between West Basin Creek and East Basin Creek, where dark gabbro of medium grain appears to cut the coarser, lighter gabbro, but a few feet away from this contact these two rocks, traced continuously between, grade into each other as elsewhere. The various rocks of the stock are always massive, and do not show evidence of mashing. Near the border a few fragments of surrounding rocks are present, but these are rare or wanting in the interior of the stock. There has been fracturing since the solidification of the stock and it is traversed by joints in several directions. Along some of these fractures the surrounding rock is extensively altered, but this alteration is local and the rocks of the stock are for the most part fresh.

At a number of localities veins of coarse-grained granite cut the

stock. These vary in width from less than one inch to six or eight inches, and contrast strongly in color and composition with the surrounding rock. Basalt and andesite dikes which are exposed at numerous places a short distance from its border do not cross the stock, nor do they occur near its center.

Minerals of the stock.—The constituent minerals of the stock, though all are not present in a single specimen, in approximate order of abundance are: plagioclase, orthoclase, augite, hypersthene, biotite, quartz, hornblende, magnetite, olivine, apatite, pyrite, and zircon. Plagioclase shows the usual albite and carlsbad twinning, and frequently zonal structure. Some of the plagioclase contains a large number of minute dark inclusions, which give it a grayish color. Small prisms of apatite, together with a few anhedrons of ferromagnesian minerals are similarly included. In composition the plagioclase varies from oligoclase to labradorite. In the diorite and quartz-diorite plagioclase is as a rule oligoclase or andesine, and in the most basic types it is labradorite. The total amount of plagioclase in the different rocks of the stock is remarkably uniform, and in most instances it constitutes from 40 per cent. to 50 per cent. of the rock. Plagioclase was among the first minerals formed.

Orthoclase, always present, and in some specimens in considerable amount, forms irregular anhedrons which fill the interstices between all the other minerals, except quartz. Some of it incloses ferromagnesian minerals, and apatite; and again it incloses plagioclase poikilitically or is microperthitic with albite. It was one of the latest minerals formed, and constitutes from 2 to 18 per cent. of the rock. Quartz occurs as irregular bodies in nearly all of the rocks of the stock, though it is wanting in some of the olivine gabbros. It reaches a maximum in the granodiorites, where it constitutes nearly 20 per cent. of the rock. In many specimens quartz and orthoclase form a micrographic intergrowth in which orthoclase exceeds quartz. The micrographic intergrowth crystallized after all other minerals had formed.

Pyroxene, though not present in every facies of the stock is, altogether, the most abundant ferromagnesian mineral. Its anhedra are for the most part irregular, but some of them approach idiomorphism. Augite and hypersthene are both present. Augite is pale violet.

buff, and is very faintly pleochroic. It is twinned parallel to the first pinacoid. Hypersthene is rather irregular in outline, is never twinned, and is less well cleaved than augite. The pleochroism varies from pale green parallel to **c** to reddish yellow parallel to **a** and **b**. The two pyroxenes are intricately intergrown and were synchronous in their crystallization which was, in some cases, contemporaneous with and in others immediately followed that of plagioclase. Some of the pyroxene is altered to bastite. An analysis of a mixture of the two pyroxenes from the olivine-gabbro (variety E) is given on p. 215.

Biotite is present in all varieties of the rock and occurs as irregular flakes of various sizes up to 2^{mm} in diameter. Biotite incloses small grains of magnetite and more rarely minute bodies of plagioclase; in many specimens it constitutes about 5 per cent. of the rock. An analysis of biotite separated from variety D is given on p. 213.

Hornblende occurs as small irregular anhedrons longer than they are wide; nearly all are fibrous, only a few sections showing the usual hornblende cleavage. It is pale-yellowish green and slightly pleochroic. A part of the hornblende is probably secondary and it may be uralite, though there is nothing in its crystal form to suggest derivation from a previous pyroxene, and it is possible that it is secondary to another hornblende. Minute inclusions of magnetite are present in the hornblende and small shreds of biotite are similarly included. Many of the rocks of Haystack Basin contain no hornblende at all, but it is the chief ferromagnesian mineral of the quartz-diorite.

Magnetite is present in all specimens constituting from 2 per cent. to 5 per cent. of the rock. It is a little more abundant in the more basic gabbros and occurs both as irregular anhedrons and idiomorphic crystals. In feldspar it is present as minute dust-like particles and also in larger bodies, but the greater portion of it is included in or associated with the ferromagnesian minerals. The chemical analysis of the rock shows that it contains considerable titanium. It crystallized partly after the plagioclase and contemporaneously with the ferromagnesian minerals.

Olivine, for the most part allotriomorphic, is present in a few of the more basic varieties of the gabbros. It is fractured and along the cracks is altered to serpentine. Some of it is completely replaced

by the serpentine, and the serpentine includes minute bodies of magnetite. In all the rocks containing olivine a portion of it occurs in small, rounded, oval, or irregular inclusions in the pyroxene, and in specimens where only a small amount of olivine is present all is so included. The quantity of olivine varies from nothing to 5 per cent.

Apatite occurs as slender prisms about .1^{mm} in length, wholly or partially included in the other minerals. In some specimens the prisms are arranged roughly parallel to one another, somewhat analogous to flow structure sometimes exhibited by lath-shaped feldspar in basalts, though the alignment is less perfect. These parallel prisms are included in plagioclase, orthoclase, and in the ferromagnesian minerals, showing that the crystallization of the apatite had begun but that the other minerals had not formed when the magma came to rest. The amount of apatite is nearly uniform and it usually constitutes about 1 per cent. of the rock. Pyrite occurs sparingly except in altered varieties where it is in part secondary. A very small amount of zircon is present in some specimens as characteristic prisms.

Description of Types of Haystack Stock

VARIETY A. ADAMELLOSE: GRANODIORITE

The most acid part of the stock covers a considerable area on the southern portion of the west spur of Baboon Mountain. It occurs near but not immediately at the edge of the stock. The rock is light gray, medium-grained, and has a smaller percentage of ferromagnesian minerals than any other of the stock rocks, hornblende, magnetite, and biotite constituting less than one-sixth of the mass. It is comparatively homogeneous in composition, although southward it grades into a more basic and more coarsely crystalline diorite.

The pinkish-white feldspar anhedra are from 3 to 5^{mm} long and the quartz is of smaller size. Hornblende is the most abundant ferromagnesian mineral, though magnetite and biotite are present.

Under the microscope the texture of the rock is seen to be hypidiomorphic granular. The minerals present in order of abundance are plagioclase, orthoclase, quartz, hornblende, biotite, magnetite, and apatite. Plagioclase occurs in nearly idiomorphic forms, tabular, parallel to the brachypinacoid. Many carlsbad twins and zonally

built crystals are present. Its composition is that of oligoclase-andesine, Ab_3An_1.

Orthoclase and quartz are relatively abundant, together nearly equalling plagioclase. Orthoclase, frequently microperthite, occurs as anhedra with a maximum length of 1^{mm}, and is also graphically intergrown with quartz. It also occurs as zones surrounding crystals of plagioclase. Quartz occurs as anhedra from 0.1^{mm} to 0.5^{mm} long.

Hornblende forms irregular anhedra, usually about 0.4^{mm} long, which inclose a large number of minute bodies of magnetite and biotite. A part of the hornblende, from its fibrous form, is believed to be secondary, possibly to pyroxene, though there is nothing in its outline which suggests the form of pyroxene and it may have been derived from an original hornblende. Biotite occurs as anhedra smaller than those of hornblende. Magnetite is included in the ferromagnesian minerals, and to a less extent in plagioclase. Long prisms of apatite are present. The order of crystallization was as follows: (1) Magnetite and apatite; (2) hornblende and biotite; (3) plagioclase; (4) orthoclase and quartz. The feldspars are slightly altered to kaolin and biotite to a lighter colored mica and to chlorite. An analysis of type A from the west spur of Baboon Mountain (See Fig. 3 p. 222) is given below:

ANALYSIS OF VARIETY A. GEO. STEIGER, ANALYST

Si_2O	65.06	H_2O-	.31
Al_2O_3	14.71	H_2O+	1.10
Fe_2O_3	2.82	TiO_2	.61
FeO	1.31	P_2O_5	.18
MgO	2.48	MnO	.18
CaO	3.43	BaO	.10
Na_2O	3.86	SrO	.05
K_2O	3.48	Total	99.68

NORM AND MODE OF VARIETY A

The norm of A calculated from the analysis is given in column I of the table below. The mode is given in column II. According to the quantitative classification this rock is adamellose. Its chemical composition closely resembles that of a quartz-mica-diorite, occurring in a stock at Crandall Basin, Hurricane Ridge, Yellowstone National

Park, described by Mr. Iddings.[1] It also resembles that of a hornblende-mica-porphyry from Cliff Creek, West Elk Mountains, Colorado, described by Dr. Whitman Cross,[2] and a mica-diorite from Lippenhof, N. Tryberg, Schwartzwald, Baden, described by Dr. G. H. Williams.[3]

I. Norm		II. Mode	
Quartz	19.50	Quartz	22.9
Orthoclase	20.57	Orthoclase	17.8
Albite	32.49	Albite	30.7
Anorthite	12.51	Anorthite	10.3
Hypersthene	4.80	Hornblende	9.7
Diopside	3.02	Biotite	4.2
Magnetite	3.02	Magnetite and Ilmenite	4.1
Ilmenite	1.22	Apatite	0.3
Hematite	0.80	Total	100.0
Apatite	0.34		
	98.27		
Water	1.41		
Total	99.68		

VARIETY B. HARTZOSE: GRANODIORITE-PORPHYRY

At the eastern edge of the stock about 30 rods north of the wagon road from Cowles to the Yellowstone Park a small tongue extends from the stock into gneiss. The specimen, taken 28 yards south of the northern edge of this tongue, is dark gray, fine-grained, and contains numerous phenocrysts of yellow feldspar, together with a smaller number of phenocrysts which appear from their form to be hornblende, but which in some cases have the luster and cleavage of mica.

Under the microscope the groundmass of the rock is seen to be composed of small interlocking anhedra of poikilitic quartz and alkali feldspar, a large number of minute pyroxene prisms, and a few anhedra of magnetite, plagioclase (oligoclase-andesine), and biotite. The porphyritic bodies, which in hand specimens appear to be crystals of single minerals, are found to consist of several minerals. These aggregations are of two kinds: those composed mainly of feldspar, and those composed mainly of ferromagnesian minerals.

[1] *Mon. XXXII*, U. S. Geological Survey, p. 261, 1889.

[2] *Fourteenth Annual Report*, U. S. Geological Survey, Part II, p. 227, 1894.

[3] *Neues Jahr.*, Band II, p. 624, 1883.

The outlines of the sections of feldspar aggregates are for the most part irregular but some are those of feldspar crystals. They vary from 0.3^{mm} to 1.5^{mm} in length. The matrix of the feldspar aggregates is mainly orthoclase and included within it are minute bodies of plagioclase, some approaching idiomorphism and showing both carlsbad and albite twinning. They are from 0.1 to 0.2^{mm} long, and are oligoclase-andesine. They penetrate one another most complexly. The plagioclase crystals of the aggregates do not lie entirely within the outlines of the orthoclase, but along its edges they penetrate the groundmass of the rock. The amount of plagioclase in the aggregates varies from 10 per cent. to 90 per cent. of the whole, and the quantity of orthoclase is reciprocal with that of the plagioclase. The other aggregates, composed mainly of ferromagnesian minerals, in some cases have outlines which strongly suggest the crystal form of hornblende. These aggregates are composed of mica, pyroxene, magnetite, feldspar, quartz, and apatite, but the proportion of these constituents varies greatly in different cases. In most sections of these aggregates, cut parallel to the *c* axis of hornblende, the minerals are arranged in rows, while in oblique sections and in those cut across the prism, the arrangement, sometimes roughly concentric, is usually quite irregular. The description of a typical section parallel to the *c* axis follows. It is 0.9^{mm} long and 0.4^{mm} wide, and is composed of mica, magnetite, feldspar, pyroxene, and quartz; mica and magnetite being most abundant. There are four belts parallel to *c* each about 0.1^{mm} wide; two of these are composed chiefly of mica, while the alternate two are chiefly magnetite. All the minerals within the aggregate are of small size, though the mica flakes are larger than the anhedra of other minerals. They are in various optical orientations; a little quartz and feldspar are present in all of the belts. Rimming these belts of mica and magnetite is a colorless border consisting of very minute anhedra of feldspar. It is 0.012^{mm} wide, and has the outline of a previous crystal. Beyond this is a fringe of minute pyroxene crystals which approach idiomorphism, and interspersed with these there is a small quantity of allotriomorphic feldspar. The inner outline of this fringe is very definite and sharp but the outer border is very irregular. Many of the crystals of pyroxene join the border of feldspar at right angles.

If the pyroxene border is a portion of the aggregate, then its outline is very irregular, but if the inner border of the pyroxene is considered as limiting the aggregate it has a definite crystal form. In other ferromagnesian aggregates rows of magnetite and mica are *en echelon*, and others are composed entirely of magnetite and feldspar, and still others of biotite and feldspar. All of them are surrounded by the fringe of minute pyroxenes.

The magmatic alteration shown by variety B is not unusual in igneous rocks of intermediate composition and is commonly regarded as showing a change in conditions after the phenocrysts formed and before the rock solidified. It is quite possible that some feldspar and hornblende had formed before the lava rose, and that when pressure was relieved they were partially or wholly dissolved, and under the new conditions recrystallized, their elements going into a number of other minerals. The mineral composition of the aggregates is not constant and could not have resulted merely from recrystallization of the original minerals without substitution.

An analysis of B taken from a point near the edge of the stock about 30 rods north of the wagon road from Cowles to the Yellowstone National Park, is given below.

ANALYSIS OF VARIETY B. GEO. STEIGER, ANALYST

SiO_2	64.09	H_2O-	0.22
Al_2O_3	16.20	H_2O+	0.44
Fe_2O_3	2.61	TiO_2	0.49
FeO	2.40	P_2O_5	0.24
MgO	2.06	MnO	0.09
CaO	4.51	BaO	0.15
Na_2O	3.88	SrO	0.03
K_2O	2.51	Total	99.92

I. Norm		II. Mode	
Quartz	19.20	Quartz	21.8
Orthoclase	15.01	Orthoclase	11.7
Albite	33.01	Albite	30.1
Anorthite	19.18	Anorthite	15.1
Hypersthene	5.82	Pyroxene	11.2
Diopside	2.08	Biotite	4.8
Magnetite	3.71	Magnetite and Ilmenite	4.9
Ilmenite	0.91	Apatite	0.4
Apatite	0.34	Total	100.0
Water	0.66		
Total	99.92		

The norm of B calculated from the analysis is given in column I of the above table. This variety is a little lower in silica, potash, and magnesia than variety A, and richer in alumina, ferrous iron, and lime, while it contains approximately an equal amount of soda and ferric iron. Its mode is given in column II of the above table. According to the quantitative classification it is hartzose and in composition closely resembles a granodiorite from Grass Valley, Nev., described by Mr. W. Lindgren.[1] It is also somewhat similar to a granite from Butte, Montana, described by Mr. W. H. Weed.[2]

VARIETY C. TONALOSE: QUARTZ-BEARING DIORITE

Southwest of the summit of Baboon Mountain and near the outer edge of the stock the rock is fine-grained, dark, and nearly aphanitic, though a few small dark minerals are visible. This rock is cut by small dikes of light-colored medium-grained granite, which are described on p. 223.

Under the microscope the rock is seen to be holocrystalline, and allotriomorphic granular. The minerals, in order of relative abundance are andesine, pyroxene, orthoclase, quartz, biotite, magnetite, and apatite. Andesine, orthoclase, and quartz occur as interlocking anhedra, varying from 0.02 to 0.04^{mm} in diameter and constituting approximately 70 per cent. of the rock. The ferromagnesian minerals are rather evenly spaced with respect to the quartz and feldspar. Pyroxene occurs in bodies from 0.02 to 0.32^{mm} in diameter, those of the smaller size being much the more numerous. The smaller bodies approach idiomorphism, while the larger ones are irregular in form. Both augite and hypersthene are present. Biotite is less abundant and occurs as foliae from 0.1 to 0.3^{mm} long. Magnetite occurs in irregular bodies the size and number of which are something less than those of biotite. Apatite is present as long prisms. The usual order of crystallization was as follows: (1) Magnetite and apatite; (2) Pyroxene, plagioclase, and biotite; (3) Orthoclase and quartz.

An analysis of C, from a specimen taken near the outer edge

[1] *Seventeenth Annual Report*, U. S. Geological Survey, Part I, p. 724, 1896.

[2] *Journal of Geology*, Vol. VII, p. 739, 1899.

of the stock, south of the summit of Baboon Mountain (see Fig. 3) is given below.

ANALYSIS OF VARIETY C. GEO. STEIGER, ANALYST

SiO_2	57.98	H_2O-	.49
Al_2O_3	17.01	TiO_2	.90
Fe_2O_3	3.34	P_2O_5	.43
FeO	3.34	NiO	trace
MgO	2.74	MnO	.12
CaO	7.35	BaO	.06
Na_2O	3.92	SrO	.02
K_2O	2.02	Total	99.86
H_2O-	.14		

The norm of C calculated from the analysis is given in column I of the table below, the mode in column II.

I. Norm		II. Mode	
Quartz	10.38	Quartz	12.1
Orthoclase	11.68	Orthoclase	9.7
Albite	33.01	Albite	31.2
Anorthite	23.07	Anorthite	20.8
Hypersthene	4.71	Pyroxene	13.5
Diopside	8.64	Biotite	6.7
Magnetite	4.87	Magnetite and Ilmenite	4.9
Ilmenite	1.67	Apatite	1.1
Apatite	1.01	Total	100.0
Water	0.63		
Total	99.72		

According to the quantitative classification this rock is a tonalose and its chemical composition very closely resembles that of a hornblende-augite-andesite from the Wind River Plateau, Yellowstone National Park, described by Hague and Jaggar,[1] and a diorite from Captains Bay, Unalaska Island, Alaska, described by G. F. Becker.[2] It is similar in composition to a large number of rocks from nearly every continent, being one of the commonest types known. It is very close to Clark's average rock for the United States, but exceeds it slightly in alumina, lime, and titania, and contains a little less magnesia and potash.[3]

[1] *Bulletin No. 168*, U. S. Geological Survey, p. 96.

[2] *Bulletin No. 148*, U. S. Geological Survey, p. 232.

[3] *Bulletin No. 78*, U. S. Geological Survey, p. 37.

VARIETY D. MONZANOSE: QUARTZ-BEARING ORTHOCLASE-GABBRO

Toward the interior of the stock the proportion of ferromagnesian minerals increases and the rock becomes more coarsely crystalline. The specimen described is a grayish-brown gabbro occurring about halfway betweeen Mud and Blue Lakes, and is composed chiefly of feldspar, pyroxene, and biotite.

Under the microscope the following minerals are seen to be present and are mentioned in the order of abundance: plagioclase, orthoclase, augite, hypersthene, magnetite, biotite, quartz, serpentine, and apatite.

Plagioclase occurs in nearly idiomorphic crystals. Carlsbad twins about 1^{mm} long are common, and some crystals show zonal structure. Both andesine and labradorite are present. Minute dust-like opaque bodies and larger ones of brown glass, with a little apatite, pyroxene, and magnetite, are included in the plagioclase. Orthoclase and quartz, micrographically intergrown, fill the interstices between other minerals. Augite is more abundant than hypersthene.

Biotite occurs as plates up to 3^{mm} in length, partly altered to hydro-biotite. An analysis of biotite separated from D is given below. Magnetite, highly titaniferous, is included in the other

ANALYSIS OF BIOTITE FROM VARIETY D. GEO. STEIGER, ANALYST

SiO_2	33.07	Na_2O	0.28
Al_2O_3	13.00	K_2O	6.11
Fe_2O_3	17.22*	H_2O-	5.41
FeO	not det.†	H_2O+	11.61
MgO	11.33		
CaO	2.45	Total	100.48

*Contains ferrous iron P_2O_5 and TiO_2. †Determined as Fe_2O_3.

minerals, and is especially abundant in the ferromagnesian constituents. A little serpentinized olivine is present. Long prisms of apatite show a tendency to parallelism. The order of crystallization was as follows: (1) Apatite and magnetite; (2) Plagioclase and the ferromagnesian silicates; (3) orthoclase and quartz. Feldspar is slightly kaolinized, hypersthene is partly altered to bastite, biotite to hydro-biotite, olivine to serpentine. An analysis of D from a specimen taken midway between Mud and Blue Lakes (see Fig. 3) is as follows:

ANALYSIS OF VARIETY D. GEO. STEIGER, ANALYST

SiO_2	54.84	H_2O-	.34
Al_2O_3	16.41	H_2O+	.93
Fe_2O_3	3.63	TiO_2	.99
FeO	4.54	P_2O_5	.35
MgO	4.71	BaO	.12
CaO	6.64	SrO	.05
Na_2O	3.27	Total	99.65
K_2O	2.83		

The norm of D is shown in column I of the following table; the mode in column II.

I. Norm		II. Mode	
Quartz	4.68	Quartz	6.8
Orthoclase	16.68	Orthoclase	15.4
Albite	28.30	Albite	27.5
Anorthite	21.41	Anorthite	19.7
Hypersthene	11.87	Pyroxene	19.5
Diopside	7.32	Olivine and Serpentine	0.5
Magnetite	5.34	Biotite	4.6
Ilmenite	1.98	Magnetite and Ilmenite	5.2
Apatite	1.01	Apatite	0.8
Water	1.27	Total	100.0
Total	99.84		

According to the quantitative system, variety D is a monzonose. It is less siliceous than those previously described and is chemically similar to an augite-andesite-porphyry from the Indian Creek laccolith, Yellowstone National Park, described by Mr. Iddings,[1] and to a diorite from Mt. Ascutney, Vt., described by Mr. R. A. Daly.[2]

VARIETY E. SHOSHONOSE: ORTHOCLASE-GABBRO

This variety occurs about a half-mile northeast of the summit of Haystack Peak and a quarter-mile west of Mud Lake, or about halfway between the western shore of this lake and the north spur of Haystack Peak. It is a dark, coarse-grained gabbro in which feldspar, pyroxene, and biotite are visible in hand specimen, the ferromagnesian minerals constituting about one-third of its volume.

Under the microscope the texture is seen to be hypidiomorphic granular; plagioclase and pyroxene approach idiomorphism; ortho-

[1] *Mon. XXXII*, U. S. Geological Survey, p. 83.

[2] *Bulletin No. 148*, U. S. Geological Survey, p. 69.

clase and quartz are poikilitic with respect to the other constituents. The minerals present in order of abundance are: andesine, augite, orthoclase, hypersthene, magnetite, biotite, quartz, apatite, and olivine.

Andesine occurs in prisms from 1 to 2^{mm} long and about 0.3^{mm} wide, and commonly as carlsbad twins. Orthoclase occurs as a matrix for plagioclase and the ferromagnesian minerals, filling the angular interstices between them. Quartz is present only as a micrographic intergrowth with orthoclase. Augite, pale violet-buff, occurs as anhedra from 0.5 to 1.5^{mm} long. Hypersthene is of the same size and is pleochroic, green parallel to **c**, and reddish yellow parallel to **a** and **b**. Both pyroxenes contain minute bodies of magnetite, biotite, and apatite, and a little serpentinized olivine, which taken together equal about 2 per cent. of the mineral. An analysis of a mixture of the two pyroxenes is given below. In the preparation of the sample the crushed and sized minerals were separated by Thoulet's heavy solution. The portion of the rock which came down at a specific gravity of 3.1, the maximum specific gravity of the solution, included, besides the pyroxenes, magnetite and bodies composed of magnetite and feldspar or pyroxene and feldspar. Those particles in which there was a considerable proportion of magnetite were removed with the magnet, and the remainder was treated with acid to remove small adhering particles of magnetite from the pyroxene. The resulting nearly pure pyroxene was recrushed, resized, and passed through the solution again, after which the treatment with the acid was repeated.

ANALYSIS OF PYROXENES FROM VARIETY E. GEO. STEIGER, ANALYST

		Molecular Proportion	Diopside	Soda Pyroxene	Alumina Pyroxene	Hypersthene	Quartz
		+TiO_2					
SiO_2.....	50.95	867	408	20	32	351	54
Al_2O_3.....	2.72	26	...	5	21	...	..
Fe_2O_3.....	1.70	11	...	..	11	...	..
FeO.....	13.87	197	69	..	11	117	..
MgO.....	15.58	390	135	..	21	234	..
		+MnO					
CaO.....	11.39	204	204	..	..	...	..
Na_2O.....	0.31	5	...	5	..	...	..
TiO.....	1.42	...	...	..	..	...	..
MnO.....	0.26	...	...	..	..	...	..
Total.....	98.19						

To ascertain the relative amounts of hypersthene and augite the following ideal compositions for the two pyroxenes were assumed:

Hypersthene $(Mg, Fe)O \cdot SiO_2$

Augite { (*a*) $CaO \cdot (Mg, Fe)O \cdot 2SiO_2$; (*b*) $Na_2O \cdot Al_2O_3 \cdot 4SiO_2$; (*c*) $(Mg, Fe)O \cdot (Al\ Fe)_2O_3 \cdot SiO_2$ }

In the adjustment the TiO_2 was regarded as isomorphous with SiO_2 and the MnO isomorphous with FeO. A quantity of silica amounting to 3.24 per cent. cannot be accounted for by any probable adjustment, and it may have resulted from decomposition of adhering feldspar after treatment with acid, the insoluble silica remaining behind. In the hypersthene, iron : magnesia as 1 : 2. In the augite, diopside (*a*): soda pyroxene (*b*): aluminous pyroxene (*c*) as 204 : 5 : 32. With this adjustment of molecules the proportion of the two pyroxenes as they occur in the specimen gives:

Hypersthene	38.84
Augite	56.12
Quartz	3.24
Total	98.20

Hypersthene is 40.91 per cent. of the pyroxene, and augite 59.09 per cent. of the pyroxene.

Biotite is present as irregular plates, and magnetite occurs as bodies up to 0.8^{mm} in diameter. Apatite occurs as prisms in all the other minerals. The order of crystallization was the same as in D. The chemical analysis of E, taken one quarter-mile west of Mud Lake (see Fig. 3) is as follows:

ANALYSIS OF VARIETY E. GEO. STEIGER, ANALYST

SiO_2	54.09	H_2O-	0.20
Al_2O_3	16.00	H_2O+	0.77
Fe_2O_3	2.92	TiO_2	0.99
FeO	5.54	P_2O_5	0.35
MgO	5.19	MnO	0.15
CaO	7.37	BaO	0.10
Na_2O	3.38	SrO	0.06
K_2O	2.67	Total	99.78

The norm of E, calculated from the analysis, is given in column I of the following table, the mode in column II.

I. Norm		II. Mode	
Quartz	1.56	Quartz	3.7
Orthoclase	16.12	Orthoclase	13.2
Albite	28.82	Albite	26.5
Anorthite	20.29	Anorthite	18.9
Hypersthene	13.88	Pyroxene	28.8
Diopside	11.22	Olivine and Serpentine	0.3
Magnetite	4.18	Biotite	3.1
Ilmenite	1.98	Magnetite and Ilmenite	4.8
Apatite	1.01	Apatite	0.7
Water	0.97		
Total	100.03	Total	100.0

Variety E is among the most basic of the Haystack rocks, and, according to the quantitative system of classification, is a shoshonose. It is closely similar to a diorite from Rock Creek, Crazy Mountains, Mont., described by Mr. J. E. Wolff,[1] and to a large number of shoshonites from the Yellowstone National Park, described by Mr. Iddings.[2] It is a little lower in potash than these rocks and richer in the ferromagnesian constituents.

VARIETY F. HESSOSE: OLIVINE–GABBRO

This variety is a dark gray, coarsely crystalline olivine-gabbro which occurs near the center of the stock. The specimen was taken near the base of the cliff southwest of Mud Lake. It is the most basic variety of the stock and is composed of feldspar, pyroxene, biotite, and olivine, the ferromagnesian minerals constituting about two-fifths of the whole.

Under the microscope the texture of the rock is hypidiomorphic granular, and the following minerals, named in relative order of abundance, are present: labradorite, augite, hypersthene, olivine, orthoclase, magnetite, biotite, and apatite. Labradorite occurs as crystals about 1^{mm} long, approaching idiomorphism, and is twinned according to albite and carlsbad laws. Orthoclase, containing a little graphic quartz, is present as irregular bodies, filling interstices between other minerals. The pyroxenes occur as anhedra from $\frac{1}{2}$

[1] *Bulletin No. 148*, U. S. Geological Survey, p. 144.

[2] *Journal of Geology*, Vol. III, and *Bulletin No. 168*, U. S. Geological Survey.

to 2^{mm} long and include a considerable amount of magnetite and minute particles of olivine and biotite. Olivine occurs as rounded or irregular bodies, in part included in pyroxene. It is partly altered to serpentine which either replaces the olivine completely, or occurs along its cracks. The fibers of the serpentine are parallel and not perpendicular to the boundaries and cracks of olivine. Biotite surrounds magnetite and is partially altered to chlorite. Small irregular grains of magnetite are present, wholly or partially included in the ferromagnesian minerals. The feldspar is almost free from magnetite. Apatite prisms are included in all the other minerals. A small amount of calcite is present.

The order of crystallization is as follows: (1) Olivine, apatite, and some magnetite; (2) some labradorite, pyroxene, more magnetite, and biotite; (3) more labradorite; (4) orthoclase and quartz. An analysis of F, from a specimen taken near the base of the cliff southwest of Mud Lake (see Fig. 3) is as follows:

ANALYSIS OF VARIETY F. GEO. STEIGER, ANALYST

SiO_2	47.87	H_2O+	1.25
Al_2O_3	16.34	TiO_2	1.02
Fe_2O_3	3.59	CO_2	.44
FeO	7.17	P_2O_5	.41
MgO	7.80	NiO	.02
CaO	10.33	MnO	.14
Na_2O	2.43	BaO	.03
K_2O	.92	Total	100.04
H_2O-	.28		

The norm of F calculated from the analysis is given in column I of the following table; the mode in column II.

I. Norm		II. Mode	
Quartz	0	Quartz	0
Orthoclase	5.56	Orthoclase	4.9
Albite	20.44	Albite	19.2
Anorthite	30.86	Anorthite	26.7
Hypersthene	12.00	Pyroxene	30.9
Diopside	14.34	Olivine and Serpentine	6.8
Olivine	6.72	Biotite	4.5
Magnetite	5.34	Magnetite and Ilmenite	5.8
Ilmenite	1.98	Apatite	1.2
Apatite	1.01	Total	100.0
Water	1.53		
Total	99.78		

Variety F is the most basic of the Haystack rocks, and, according to the quantitative classification, is hessose. In composition it resembles an olivine-basalt from Franklin Hill, Plumas County, California, described by Mr. H. W. Turner,[1] an augite-diorite from Stony Mountain, Ouray County, Colorado, described by Dr. Whitman Cross,[2] and a basalt from Prospect Peak, Yellowstone National Park, described by Mr. Iddings.[3]

Chemical variation of varieties.—The analyses of the six varieties are given in the table below. The combining molecules of the rocks which

ANALYSIS OF TYPES OF HAYSTACK STOCK. GEO. STEIGER, ANALYST

	A	B	C	D	E	F
SiO_2	65.06	64.09	57.98	54.84	54.09	47.87
Al_2O_3	14.71	16.20	17.01	16.41	16.00	16.34
Fe_2O_3	2.82	2.61	3.34	3.63	2.92	3.59
FeO	1.31	2.40	3.34	4.54	5.54	7.17
MgO	2.48	2.06	2.74	4.71	5.19	7.80
CaO	3.43	4.51	7.35	6.64	7.37	10.33
Na_2O	3.86	3.88	3.92	3.27	3.38	2.43
K_2O	3.48	2.51	2.02	2.83	2.67	0.92
H_2O-	0.31	0.22	0.14	0.34	0.20	0.28
H_2O+	1.10	0.44	0.49	0.93	0.77	1.25
TiO_2	0.61	0.49	0.90	0.99	0.99	1.02
CO_2	.....	.....	.....	.....	.....	0.44
P_2O_5	0.18	0.24	0.43	0.35	0.35	0.41
NiO	.....	.....	trace	.....	.....	0.02
MnO	0.18	0.09	0.12	.....	0.15	0.14
BaO	0.10	0.15	0.06	0.12	0.10	0.03
SrO	0.05	0.03	0.02	0.05	0.06	.....
Total	99.68	99.92	99.86	99.65	99.78	100.04

have been analyzed, arranged according to the increase of silica, are shown in Fig. 2. Silica is platted as the abscissa and 798 combining molecules are taken as an initial point. The alkalies, alkali earths, alumina, and iron are taken as ordinates. The diagram shows graphically the irregularity in the variation of the oxides. Alumina shows little variation, about the same quantity being present in all analyses. Its total range of variation is but 23 molecules. The granodiorite A is least aluminous. None of the oxides vary directly or inversely with alumina, which is higher than any of the

[1] *Seventeenth Annual Report*, U. S. Geological Survey, Part I, p. 734.

[2] *Bulletin No. 148*, U. S. Geological Survey, p. 180.

[3] *Mon. XXXII*, U. S. Geological Survey, p. 438.

other oxides except silica and lime and magnesia, at the basic end of the diagram. Ferrous and ferric iron are in a measure inversely proportional to each other, an increase in one usually being accompanied by a decrease in the other. The total amount of iron decreases irregularly to the more siliceous end of the series. Magnesia also decreases rapidly as the silica increases and this decrease more nearly agrees with that of the ferrous than of the ferric iron. Lime,

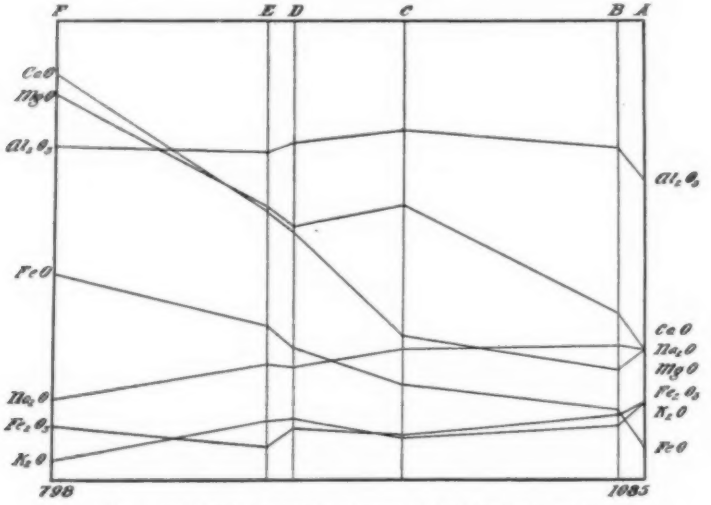

FIG. 2.—Chemical variation of types of the Haystack stock.

like magnesia, decreases steadily from the less siliceous toward the more siliceous end of the series, but increases slightly in the granodiorite at the extreme end. The soda, low in F, increases gradually and steadily to B, and falls slightly in A. Potash increases very irregularly to the more siliceous end of the diagram. The alkalies vary neither directly nor reciprocally with each other, though both increase with silica.

Mr. H. S. Washington,[1] in discussing the differentiated complex at Magnet Cove, Ark., ranges six analyses in order of ascending silica. In his diagram with but one exception the oxides increase

[1] *Bulletin of the Geological Society of America*, Vol. XI, p. 404.

or decrease with the silica. The variations of the oxides in the Haystack series, with respect to silica and to each other, are much less regular than is the series at Magnet Cove. This is well illustrated by the crossing descending lines in the diagram.

Probable average composition of stock.—The average composition of the six analyzed varieties of the Haystack stock is as follows:

AVERAGE CHEMICAL COMPOSITION OF THE SIX ANALYZED VARIETIES

SiO_2	57.32	H_2O+	0.83
Al_2O_3	16.11	TiO_2	0.83
Fe_2O_3	3.15	CO_2	0.07
FeO	4.05	P_2O_5	0.33
MgO	4.16	MnO	0.11
CaO	6.61	BaO	0.09
Na_2O	3.46	SrO	0.03
K_2O	2.40		
H_2O-	0.25	Total	99.80

NORM OF THE AVERAGE OF THE SIX ANALYZED VARIETIES

Quartz	8.58	Magnetite	4.41
Orthoclase	14.46	Ilmenite	1.52
Albite	29.34	Water	1.08
Anorthite	21.13	Fluorine	0.67
Diopside	8.51		
Hypersthene	10.37	Total	100.07

This is probably very close to the average composition of the stock, and is perhaps as good an estimate as could be made with the data at hand. Its composition closely resembles that of a large number of orthoclase-gabbro-diorites, andesites, and related rocks from Crandall Basin and Sepulcher Mountains, described by Mr. Iddings,[1] a number of monzonites and andesites from Colorado, described by Dr. Whitman Cross,[2] and diorites from Mt. Ascutney, Vt., described by Mr. R. A. Daly.[3] Of the Haystack rocks the average is nearest C, which is a contact facies of the stock.

Asymmetry of the stock.—The map (Fig. 1) shows that the Haystack stock is asymmetrical. The stock is also asymmetrical with respect to its composition. Fig. 3 is a sketch map which shows the

[1] *Mon. XXXII*, U. S. Geological Survey, Part II.

[2] *Bulletins 1* and *168*, U. S. Geological Survey.

[3] *Bulletin 148*, U. S. Geological Survey, p. 69.

location of the rocks analyzed. The most basic (F) is not at the center of the stock, but southeast of it, and the most acid variety (A) is farther from F than the edge of the stock in several other directions. Moreover, the diorite south of F or between F and the border toward the south is less acid than A, though it is much more acid than F. It will hold true, however, that if lines are drawn to the border radiating from F, the composition of the stock along these lines becomes gradually more acid, though at different rates, and

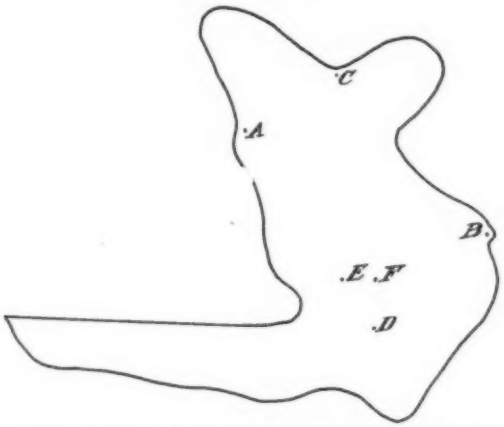

FIG. 3.—Outline of Haystack stock. The letters show the position of analyzed types.

some portions of the periphery are more acid than others. The modes of the six varieties are tabulated below, A, B, and C are the

MODES OF VARIETIES OF HAYSTACK STOCK

	A	B	C	D	E	F
Quartz	22.9	21.8	12.1	6.8	3.7	....
Orthoclase	17.8	11.7	9.7	15.4	13.2	4.9
Albite	30.7	30.1	31.2	27.5	26.5	19.2
Anorthite	10.3	15.1	20.8	19.7	18.9	26.7
Hornblende	9.7	....	....	....	....	....
Pyroxene	....	11.2	13.5	19.5	28.8	30.9
Biotite	4.2	4.8	6.7	4.6	3.1	4.5
Olivine and Serpentine	....	....	....	0.5	0.3	6.8
Magnetite and Ilmenite	4.1	4.9	4.9	5.2	4.8	5.8
Apatite	0.3	0.4	1.1	0.8	0.7	1.2

peripheral acid varieties, while D, E, and F are the basic central varieties. This table shows that quartz is present in the outer border of the stock in largest amount, and decreases toward the center of the stock. Orthoclase is present in every case, but is most abundant in the facies not far from the periphery. Plagioclase is present in approximately the same amount in all varieties, but is more calcic in the central ones. Pyroxene is least abundant near the periphery, and most abundant in the most basic facies near the center of the stock. Hornblende, in part probably secondary to pyroxene, is relatively abundant only in the most acid portion near the periphery. Olivine is abundant only in the most basic varieties near the center. Biotite and magnetite are fairly uniform in quantity.

The order of crystallization of the minerals of the stock, briefly summarized, is as follows:

1. Apatite, crystallized first, since it occurs in all the other minerals.

2. The ferromagnesian minerals, pyroxene, hornblende, biotite, magnetite, and olivine, crystallized early but mainly after apatite had formed.

3. Plagioclase, crystallized after apatite, after and along with the ferromagnesian minerals.

4. Orthoclase and quartz, crystallized together after plagioclase and the ferromagnesian minerals had formed.

GRANITE (OMEOSE) VEINS CUTTING THE HAYSTACK STOCK

Granite veins one-half inch to six inches wide cut various rocks of the Haystack stock. These occur at the base of the cliff of the southeast of Blue Lake, on the southwestern slope of Baboon Mountain near the summit, on the wagon road from Cowles to the Yellowstone National Park about two hundred and fifty yards east of the divide in Haystack Basin, and at many other localities. The granite is everywhere from medium to coarse-grained, and is lighter colored than the rock it cuts. The granite is composed of feldspar and quartz with a little biotite and hornblende. The veins do not appear to be persistent in length, since they cannot be traced continuously for any great distance. A specimen from a 2-inch vein cutting a very dark fine-grained quartz-bearing diorite (C) on the southwest slope of Baboon Mountain is a pinkish gray, medium-grained rock.

Under the microscope the following minerals are present in the order of their abundance: alkali feldspar, quartz, andesine, magnetite, hornblende, and biotite. The alkali feldspar is orthoclase, microperthitically intergrown with albite, and occurs as anhedra which reach a maximum diameter of 2.4^{mm}. Quartz occurs as irregular anhedra of equal size interlocking with orthoclase and sometimes as a graphic intergrowth. A small amount of andesine (Ab_3 An_2) is present, as slender laths about 0.5^{mm} long. These laths are concentrated along the margin of the vein and in many cases their long axes are normal to the contact. Anhedra of magnetite as large as 0.5^{mm} in diameter, fibrous green hornblende, and biotite are included in orthoclase and quartz. Biotite is slightly altered to chlorite.

The contact of intruding and intruded rock is sharp in the hand specimen, but under the microscope these two rocks appear to grade into each other within a zone about 0.2^{mm} wide. In this zone some of the quartz of the intruding rock appears to have attached itself with similar optical orientation to quartz in the intruded rock. In the crystallization of the veins magnetite, hornblende, biotite, and plagioclase were formed before alkali feldspar and quartz, and the latter two crystallized synchronously. Perhaps all of the minerals, except alkali feldspar and quartz had formed before the intrusion, but if so the magma must have been very fluid, since these minerals do not show flow structure and since the long axes of the plagioclase laths, more frequently than otherwise, make a large angle with the walls.

The composition of the granite veins is not far from that of the micrographic intergrowth of quartz and orthoclase which solidified last in nearly all of the Haystack rocks. The veins were probably formed during the latter stages of the solidification of the rocks they cut, and may represent the liquid portion of the magma after most of the plagioclase and nearly all of the ferromagnesian minerals had crystallized out. Even the smallest veins are very coarse grained and must have cooled slowly. This suggests that they were intruded while the rock which they cut was still hot, or that their water content was sufficiently high to permit the growth of large crystals. The cracks they fill are probably shrinkage cracks formed directly after solidification of the rock.

The mode of the granite is as follows:

Quartz	25.51	Biotite	2.78
Alkali feldspar	60.70	Magnetite	3.50
Andesine (Ab_3An_2)	4.09		
Hornblende	3.42	Total	100.00

From this mode the following chemical constitution is estimated:

SiO_2	70.38	CaO	.75
Al_2O_3	13.17	Na_2O	2.10
Fe_2O_3	2.74	K_2O	7.99
FeO	1.87		
MgO	.73	Total	99.73

From a study of thin sections it is estimated that the alkali feldspar is 15.17 albite and 45.52 orthoclase and that the plagioclase is andesine, Ab_3An_2. It is assumed that the hornblende is chemically like that from a quartz-monzonite, at Mt. Hoffman, Colo., and that the biotite is chemically like that from a granodiorite at El Capitan, Yosemite Valley, Cal.

The norm of the granite vein calculated from the estimated composition is,

Quartz	24.50	Hypersthene	2.65
Orthoclase	47.26	Diopside	.68
Albite	17.82	Magnetite	3.94
Anorthite	2.78	Total	99.67

According to the quantitative classification the rock is omeose. In composition it closely resembles a granite from Currant Creek Canyon, Pike's Peak, Colo., described by Mr. E. B. Mathews,[1] a graphic granite from Omeo, Victoria, described by Mr. A. W. Howitt,[2] and a rhyolite from Round Mountain, Rosita Hills, Colo., described by Dr. Whitman Cross.[3] It is not far from the composition of micropegmatite estimated by Mr. J. J. H. Teall from a vein-cutting diabase near Kington.[4]

GENESIS OF THE ROCKS OF THE STOCK

The gradational character of the various rocks of the Haystack stock shows that it is geologically a unit and should be classed with

[1] *Bulletin No. 148*, U. S. Geological Survey.

[2] *Transactions of the Royal Society of Victoria*, Vol. XXIV, p. 120.

[3] *Proceedings of the Colorado Scientific Society*, Vol. II, p. 33.

[4] *British Petrography*, p. 401.

such bodies as are assumed to have resulted from the differentiation of a single magma. The various rocks must be regarded as essentially of the same age, since they are not separated by sharp contacts, as is the case where an igneous rock is intruded by a later one.

Gradational series of rocks have been recognized and described by a large number of observers. Those who have attempted to explain the phenomenon are in the main agreed that the differences in composition have been brought about through differences of temperature and pressure, or by the direct operation of gravity during crystallization. For some differentiated bodies it is assumed that these processes operated after the homogeneous magma had risen to the place at which the rocks now occur, while for other bodies the magma appears to have been of heterogeneous composition before it rose to its final resting place. These processes have been reviewed comprehensively by Professor L. V. Pirsson, in a recent publication by the U. S. Geological Survey,[1] and to do so here would largely be repetition. Some of them will be briefly stated however and examined not with regard to their general application but with especial reference to the Haystack stock.

Falling of crystals.—The simplest theory to account for differences in an igneous body which supposedly was once homogeneous is to assume that, of the minerals crystallizing first, the heavier ones sink, and the lighter ones rise much as the constituent minerals of rocks are separated in heavy solutions in the laboratory. Schweig[2] has made the suggestion that heavy crystals formed in the early stages of rock solidification, fall, and are remelted, thus changing the composition of the magma at different depths. For the operation of the process the viscosity of the magma must not be too great to allow minerals to settle by their own weight. Magnetite, the heaviest mineral in the Haystack stock, was also one of the first to solidify, and it is present in all varieties in nearly the same quantity; consequently at the time crystallization began the magma must have been too viscous for magnetite to fall.

The ferro magnesian minerals, which are much heavier than the feldspars, are most abundant in the central portion of the stock

[1] *Bulletin No. 237*, p. 183.

[2] *Neues Jahrbuch für min. Beil.*, Bd. 17, p. 516.

(D, E, F, Fig. 3), while the feldspars and quartz predominate in the rocks around the border (A, B, C). Variety B, containing 78 per cent. of quartz and feldspars, occurs at approximately the same elevation as F, which contains only 50 per cent. of quartz and feldspar. If differentiation occurred after the magma had reached the place at which the rocks are now exposed it was such that the elements forming the ferromagnesian minerals moved toward the center of the stock rather than downward in the stock. Accordingly the falling of the heavy crystals does not appear to have been an important process after the magma rose to the place at which the rocks are exposed.

Fractional crystallization.—Certain intrusive masses appear to have differentiated into rocks of various compositions by simple crystallization during cooling. Since the outer portion of an intrusive body is nearer the colder rocks into which it is thrust, this portion of the intrusive is supposed to solidify first, and the minerals which form first in the rocks would form first of all in the outer zone, and having once commenced to crystallize they would continue to grow while the more soluble constituents would be crowded to the center of the stock. This process, according to Mr. H. S. Washington, accounts for the gradational series of rocks which form the igneous complex at Magnet Cave, Arkansas.[1]

As is shown by the order of crystallization of the minerals (p. 223) quartz and orthoclase formed after the ferromagnesian minerals and plagioclase. If differentiation had been brought about by the process of fractional crystallization, the types in which quartz and orthoclase are present in greater abundance should be the types which were last to form, but the reverse is true if the outer portion of the stock solidified first, for the border varieties A, B, C contain a much larger proportion of quartz and orthoclase and a much smaller proportion of the ferromagnesian minerals than the varieties D, E, F, which occur near the center.

Fractional crystallization with convection currents.—According to Becker,[2] gradational series of rocks which constitute certain dikes and laccoliths can have been formed only through fractional crystal-

[1] *Bulletin of the Geological Society of America*, Vol. XI, p. 390.

[2] *American Journal of Science*, 4th Ser., Vol. III, p. 21.

lization with convection currents which during crystallization serve to keep the still liquid central portion of the mass of uniform composition. The least soluble minerals will go out of solution first and these will form around the outer portion of the stock, while the liquid magma inside continues to supply like material which it deposits on the walls as it moves by them. Applied to the Haystack stock this hypothesis is open to the same objections as the one previously discussed for the minerals which are most abundant in the rocks forming the periphyry are those which formed last in all the rock types of the stock.

Differentiation prior to intrusion.—Intrusive masses made up of a gradational series of rocks not showing a zonal arrangement across the outcrop are of common occurrence and in most cases they seem to have resulted from differences in the composition of the magma before it came to rest. Mt. Johnson, of the Montenegran Hills, which has been described by Dr. F. D. Adams[1] belongs genetically to the same class, although it is composed of a hollow cylinder of laurvikose inclosing a smaller hollow cylinder of andose, which in turn incloses a cylinder of essexose, the three types grading each into the other. Dr. Adams concludes that before the lava reached its present position, a reservoir somewhere below the mountain had differentiated into a liquid mass of which the heavier portion had the composition of essexose, the upper portion laurvikose, and the central portion andose. The upper portion rising first would form the outer cylinder which in turn would be filled or intruded by andose. Subsequently that would be intruded by essexose. Accordingly the arrangement of the rocks from the bottom up in the earlier body would be the same as that from the center out in the later one. Although the zones are not so well defined in the Haystack stock the rocks of the lowest specific gravity occur near the outer portion of the stock, while the heavier varieties, D, E, and F are near the central portion.

Since no process of magmatic differentiation appears to have operated after the intrusion to form the gradational series of the Haystack stock, it is probable that the differentiation occurred before the magma was intruded and that the basic central portion represents a magma which was erupted after the more acid portion,

[1] *Journal of Geology*, Vol. XI, p. 22.

but that the eruptions followed each other so closely that the magma of one type had not solidified before a magma of different composition rose through it. The resulting rock mass was therefore, a gradational series of rocks rather than a complex of distinctly different intersecting rocks.

SOME IGNEOUS ROCKS FROM THE ORTIZ MOUNTAINS, NEW MEXICO

I. H. OGILVIE
With Chemical Analyses by M. W. Adams

The Ortiz Mountains are a deeply sculptured laccolith, lying on the San Pedro quadrangle, some twenty-five miles east of Albuquerque. They are roughly circular in outline with a diameter of about five miles, and have a relief of about 3,000 ft., the highest peak rising to an altitude of 8,998 ft. They afford interesting data on erosion in an arid climate; on Mesozoic stratigraphy and paleontology; on the events of the Pleistocene period in the region south of the ice sheets; and on petrology. The present paper is preliminary, and deals with a few of the more conspicuous rock types.

The quantitative system is used in classification, the names being based on analyses. The following table indicates the rock types represented.

TABLE I

Class	Order	Rang	Subrang	Old Name
I. Persalane.....	4. Canadare-Britannare	2. Toscanase	4. Lassenose	Dacite
		3. Coloradase	4. Yellowstonose	Dacite
II. Dosalane.....	5. Germanare	2. Monzonase	3. Monzonose	Diorite
			4. Akerose	Diorite
		3. Andase	4. Andose	Diorite
III. Salfemane.....	6. Norgare	2. Essexase	4. Essexose	Essexite
	5. Gallare	4. Auvergnase	3. Auvergnose	Andesite

The distribution of these types is found to be noteworthy: The main mass of the laccolith is of the more femic types, essexose and Auvergnose (andesites); the sheets which border the mass are of the most salic types, the persalanes (dacites); while the spurs and flanks of the mountains, lying between the above are of the intermediate types. It should however be noted that all of the rocks are intermediate when compared with igneous rocks in general.

This laccolith is the largest of four, lying in a north and south line. The northernmost, the Cerrillos Hills, has been described by D. W. Johnson.[1] The Ortiz is the next group, while the San Pedro and the South Mountains make up the southernmost groups. It is apparent that these groups are closely related and they probably constitute a single comagmatic region.

The scope of the present paper is primarily chemical. A brief statement of field relations, texture, and mineralogy will be given for each type analyzed, but a detailed discussion of optical characters will not be undertaken in this preliminary paper. It is probable that all the types here discussed are of post-Cretaceous age.

Laurvikose—Lassenose I. 4–5.2.4 (Dacite)

Rocks of this type are gray, porphyritic, and form sheets on all sides of the main mass. The phenocrysts are of pink or white feldspar, the ground mass is phanerocrystalline but fine-grained.

Microscopically the phenocrysts are found to be soda orthoclase with more or less concentric structure. A few phenocrysts of green

TABLE II

Chemical Composition of Lassenose

	I	Mol. Prop.	II	Mol. Prop.	Norms	I	II
SiO_2.....	63.11	1.052	62.36	1.039	Qu.....	12.72	11.76
Al_2O_3....	16.75	0.164	17.78	0.175	Or.....	20.57	20.02
Fe_2O_3....	2.68	0.017	2.74	0.017	Ab.....	39.82	39.82
FeO.....	1.39	0.019	1.66	0.024	An.....	14.18	17.51
MgO.....	1.22	0.040	1.37	0.034	Diop...	4.32	2.38
CaO.....	3.88	0.070	4.49	0.080	Hyp....	2.00	2.30
Na_2O....	4.76	0.076	4.75	0.076	Mag...	2.32	3.94
K_2O.....	3.48	0.037	3.37	0.036	Hem...	1.12	
H_2O+...	1.09	.....	0.26	.....	Ilm....	1.52	1.37
H_2O-...	0.32	.....	0.11	.....	Ap.....	0.34	0.67
CO_2.....	none	.....	none	.....			
TiO_2.....	0.80	0.010	0.73	0.009			
ZrO_2.....	none	.....	none	.....			
P_2O_5.....	0.25	0.001	0.29	0.002			
S.....	0.03	.....	0.03	.....			
MnO.....	0.11	0.001	0.12	0.002			
BaO.....	0.16	0.001	0.03	.....			
Total..	100.03		100.09				

[1] *School of Mines Quarterly*, 1903–4.

hornblende and of quartz may also be seen. The ground mass consists of fine grains of plagioclase with augite and magnetite.

Analyses 1 and 2 were from specimens taken from two sheets, respectively on the west and the southwest of the group. It is noteworthy that all of the FeO is in magnetite and ilmenite and that the normative diopside and hypersthene are of a pure magnesian variety. The second analysis is close to a division line in both order and rang, so this type is properly a Laurvikose-Yellowstonose-Lassenose. Norm and mode agree fairly well.

Yellowstonose. I. 4. 3. 4 (Dacite)

This type is in all megascopic and microscopic respects similar to the Lassenose. It is a porphyritic dacite, and occurs in sheets. The sole important difference is that potash, and hence the sum of the alkalies, is lower in Yellowstonose, thus placing the rock in rang 3, in spite of the fact that lime and soda are present in approximately equal amounts in both types. The second analysis (IV) approaches rang 2 and might be termed a Lassenose-Yellowstonose.

The sheets from which specimens for analysis were taken are respectively on the northeast and southeast sides of the mountains.

TABLE III

Chemical Composition of Yellowstonose

	III	Mol. Prop.	IV	Mol. Prop.	Norms	III	IV
SiO_2	62.48	1.041	62.61	1.032	Qu	15.06	16.98
Al_2O_3	18.07	0.177	17.54	0.172	Or	12.79	12.79
Fe_2O_3	2.61	0.016	2.72	0.017	Ab	39.82	41.39
FeO	1.97	0.028	1.52	0.021	An	21.08	19.46
MgO	1.34	0.034	1.39	0.035	Diop	0.22	.....
CaO	4.67	0.084	4.18	0.075	Hyp	4.12	3.50
Na_2O	4.69	0.076	4.88	0.079	Mag	3.71	3.48
K_2O	2.16	0.023	2.21	0.023	Ilm	1.22	1.22
H_2O+	0.52	.....	1.52	.....	Ap	0.67	0.67
H_2O-	0.12	.....	0.22	.....	Hem	.....	.48
CO_2	none	.....	none	.....			
TiO_2	0.60	0.008	0.60	0.008			
ZrO_2	none	.....	none	.....			
P_2O_5	0.28	0.002	0.27	0.002			
S	0.03	.....	0.06	.....			
MnO	0.17	0.002	0.14	0.002			
BaO	0.09	0.001	0.18	0.001			
Total	99.79		100.04				

SHOSHONOSE-MONZONOSE-AKEROSE-ANDOSE. II. 5. 2–3. 3–4. (DIORITE)

This rock is gray, fine-grained, and holocrystalline. It is not porphyritic. The specimen from which the analysis was made is from a spur of about 7,500 feet in altitude on the southeastern side of the group.

Chemically the type is remarkable in being exactly on the division line between rangs 2 and 3, and nearly so between subrangs 3 and 4. Hence the complex name.

Microscopically it contains orthoclase, two plagioclases, augite, a green pleochroic hornblende, titanite, magnetite, apatite, and a small amount of nepheline.

TABLE IV

CHEMICAL COMPOSITION OF SHOSHONOSE-MONZONOSE-AKEROSE-ANDOSE

	V	Mol. Prop.		Norm
SiO_2	55.04	0.917	Or	25.58
Al_2O_3	20.45	0.200	Ab	36.15
Fe_2O_3	2.09	0.013	An	20.85
FeO	2.71	0.038	Ne	2.84
MgO	1.63	0.041	Di	4.48
CaO	5.82	0.104	Ol	2.84
Na_2O	4.92	0.079	Mg	3.02
K_2O	4.29	0.046	Ilm	2.28
H_2O+	0.69	.....	Ap	1.01
H_2O-	0.10	.....		
CO_2	none	.....		
TiO_2	1.17	0.015		
ZrO_2	none	.....		
P_2O_5	0.37	0.003		
S	0.04	.....		
MnO	0.26	0.004		
BaO	0.19	0.001		
Total	99.77			

AKEROSE. II. 5. 2. 4 (DIORITE)

The type is essentially similar to the last, except that its color is pinker in tone, due to the presence of considerable red orthoclase. No nepheline is present, but there is a small amount of quartz. It forms the mountain 8,200 feet high on the southeastern side of the group.

TABLE V

CHEMICAL COMPOSITION OF AKEROSE AND ANDOSE

	VI	MOL. PROP.	VII	MOL. PROP.	VIII	MOL. PROP.
SiO_2	57.70	0.961	55.46	0.924	54.86	0.914
Al_2O_3	19.63	0.192	18.15	0.178	19.33	0.189
Fe_2O_3	3.30	0.021	3.93	0.024	3.35	0.021
FeO	1.60	0.022	3.42	0.047	2.59	0.036
MgO	1.21	0.030	3.19	0.080	3.05	0.076
CaO	5.14	0.091	7.37	0.132	7.69	0.138
Na_2O	5.42	0.087	3.44	0.055	4.38	0.071
K_2O	3.74	0.039	2.14	0.022	2.33	0.024
H_2O+	0.24	.....	0.38	.....	0.80	.....
H_2O-	0.13	.....	0.24	.....	0.16	.....
CO_2	none	.....	none	.....	none	.....
TiO_2	1.10	0.014	1.20	0.015	1.32	0.016
ZrO_2	none	.....	none	.....	none	.....
P_2O_5	0.29	0.002	0.38	0.003	0.41	0.003
S	0.06	0.002	0.04	.....	0.06	.....
MnO	0.17	0.001	0.21	0.003	0.22	0.003
BaO	0.09	0.001	0.07	.....	0.17	0.001
Total	99.77		99.62		100.72	

NORMS	VI	VII	VIII
	Akerose	Andose	Andose
Qu	1.38	8.82	2.58
Or	21.68	12.23	13.34
Ab	45.59	28.82	37.20
An	18.35	28.08	20.13
Diop	4.32	4.85	7.81
Hyp	1.00	7.16	4.23
Hem	1.92	....	....
Mag	2.09	5.57	4.87
Ilm	2.13	2.28	2.43
Ap	.67	1.01	1.01

Andose. II. 5. 3. 4 (Diorite)

This rock is in most respects identical with the preceding types but differs in having a tendency toward a porphyritic texture. It forms the massif of Lone Mountain, a partially isolated peak to the southeast of the Ortiz group. Its consanguinity with the main stock is evident from the analyses. Two of these were made, from the top and side respectively, and these are given in the preceding table. They are placed next the Akerose for comparison, this latter type being most closely related chemically and also the nearest in space. The most noteworthy differences are the higher lime and lower potash of the Andose.

Essexose. II. 6. 2. 4 (Diorite and Essexite)

This rock type is an exceedingly common one, and is somewhat variable. It forms the outlying hills on the southeast, and usually forms the top of those with an altitude of about 8,300 feet. It is from one of these that X is taken. IX is from the top of the highest mountain. The recalculated analysis requires nepheline. This is sometimes present in the slides; more often a porphyritic structure

TABLE VI

Chemical Composition of Essexose

	IX	Mol. Prop.	X	Mol. Prop.	Norms		
						IX	X
SiO_2.....	51.42	0.857	51.19	0.850	Or.....	23.91	28.36
Al_2O_3....	19.40	0.190	21.16	0.208	Ab.....	22.01	18.34
Fe_2O_3....	3.72	0.023	2.85	0.018	Ne.....	12.21	15.34
FeO.....	3.33	0.046	2.31	0.032	An.....	17.24	19.18
MgO.....	2.56	0.064	2.34	0.059	Diop....	14.48	8.86
CaO.....	7.80	0.139	6.79	0.121	Ol.....	0.90	1.26
Na_2O....	5.28	0.085	5.43	0.088	Mag....	5.34	4.18
K_2O.....	3.96	0.043	4.78	0.051	Ilm....	2.74	3.04
H_2O+...	0.49	.....	0.54	.....	Ap.....	1.34	1.34
H_2O-...	0.04	.....	0.08	.....			
CO_2.....	none	.....	none	.....			
TiO_2.....	1.39	0.018	1.54	0.020			
ZrO_2.....	none	.....	none	.....			
P_2O_5.....	0.53	0.004	0.62	0.004			
S.....	0.03	.....	0.04	.....			
MnO.....	0.23	0.003	0.25	0.004			
BaO.....	0.21	0.001	0.11	0.001			
Total..	100.39		100.03				

is developed with large phenocrysts of olivine and no nepheline. The olivine phenocrysts contain inclusions of magnetite, apatite, biotite, plagioclase; a few phenocrysts of twinned augite are occasionally present. In this variety the groundmass contains intergrowths of feldspars, and broad laths of both orthoclase and plagioclase. The nepheline-bearing variety has a granitic texture, and lacks olivine.

Auvergnose III. 5. 4. 3 (Andesite)

This rock is holocrystalline, dark-bluish gray, and contains many basic segregations. It occupies the central part of the group and lower levels of the surrounding hills whose tops are less basic.

TABLE VII

Chemical Composition of Auvergnose

	XI	Mol. Prop.	Norm	XI
SiO_2	49.09	0.818	Or	2.22
Al_2O_3	15.11	0.148	Ab	27.25
Fe_2O_3	0.48	0.003	An	25.58
FeO	7.85	0.110	Diop	22.07
MgO	7.66	0.191	Hyp	4.65
CaO	11.03	0.196	Ol	9.08
Na_2O	3.24	0.052	Mag	0.70
K_2O	0.37	0.004	Ilm	6.54
H_2O+	0.39	.....	Ap	0.67
H_2O-	0.02	.....		
CO_2	none	.....		
TiO_2	3.40	0.043		
ZrO_2	none	.....		
P_2O_5	0.34	0.002		
S	0.06	.....		
MnO	0.25	0.004		
BaO	none	.....		
Cr_2O_3	0.04	.....		
Total	99.33			

In the following table the analyses are compared. The range of silica is moderate, from 63 to 49 per cent. Alumina is generally high and its range is not great. Iron and magnesia are uniformly low and of slight range, with the exception of II, Auvergnose. Lime is high and of great range; soda is moderate and of little range; potash is moderate and of considerable range. Titanium is almost invariably high; zirconia is entirely absent; baryta is high.

TABLE VIII

		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	TiO_2	P_2O_5	S	MnO	BaO	Total
1	I.4.24	63.11	16.75	2.68	1.39	1.22	3.88	4.76	3.48	1.09	0.32	0.80	0.25	0.03	0.11	0.16	100.03
2	I.4.2.4	62.36	17.78	2.74	1.66	1.37	4.49	4.75	3.37	0.26	0.11	0.73	0.29	0.03	0.12	0.03	100.09
3	I.4.3.4	62.48	18.07	2.61	1.97	1.34	4.67	4.69	2.16	0.52	0.12	0.60	0.28	0.03	0.17	0.09	99.79
4	I.4.3.4	62.61	17.54	2.72	1.52	1.39	4.18	4.88	2.21	1.52	0.22	0.60	0.27	0.06	0.14	0.18	100.04
5	II.5 (2–3)(3–4)	55.04	20.45	2.09	2.71	1.63	5.82	4.92	4.29	0.69	0.10	1.17	0.37	0.04	0.26	0.19	99.77
6	II.5.2.4	57.70	19.63	3.30	1.60	1.21	5.14	5.42	3.74	0.24	0.13	1.10	0.29	0.06	0.17	0.09	99.77
7	II.5.3.4	55.46	18.15	3.93	3.42	3.19	7.37	3.44	2.14	0.38	0.24	1.20	0.38	0.04	0.21	0.07	99.62
8	II.5.3.4	54.86	19.33	3.35	2.59	3.05	7.69	4.38	2.33	0.80	0.16	1.32	0.41	0.06	0.22	0.17	100.72
9	II.6.2.4	51.42	19.40	3.72	3.33	2.56	7.80	5.28	3.96	0.49	0.04	1.39	0.53	0.03	0.23	0.21	100.39
10	II.6.2.4	51.19	21.16	2.85	2.31	2.34	6.79	5.43	4.78	0.54	0.08	1.54	0.62	0.04	0.25	0.11	100.03
11	III.5.4.3	49.09	15.11	0.48	7.85	7.66	11.03	3.24	0.37	0.39	0.02	3.40	0.34	0.06	0.25	none[1]	99.33

NOTE.—CO_2 and ZrO_2 being lacking in all of the analyses are not tabulated.

[1] Cr_2O_3 .04.

The Lassenoses and Yellowstonoses contain small amounts of gold, copper, antimony, lead, and bismuth.

A consideration of the serial chemical characters of the region brings out the fact that soda is practically constant and alumina nearly so. As silica decreases iron and magnesia increase but very slightly, and somewhat irregularly; on the other hand the increase in lime is regular and normal. Potash varies from 0.39 to 4.78, and its variations bear no definite relation to the decrease in silica, nor does the sum of the alkalies uniformly change. The sum of the alkalies invariably either equals or exceeds salic lime, which finds expression in the rang.

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DISCOID CRINOIDAL ROOTS AND CAMAROCRINUS

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Since the writings of Wachsmuth and Springer,[1] and of Bather[2] have given an increased scientific interest to fossil Crinoidal roots or stem bases, fossils of this sort which occur in the Galena (Trenton) stage of the Ordovician in Minnesota, have been collected by me with some especial care. In particular, certain disc-shaped roots have been collected and studied. These are believed to represent the primitive form and structure of Crinoidal roots, and are of special interest for that reason, as also because they are rare and little known. Few fossils of this kind have been described heretofore. Since my collection represents a relatively large number, about 100 specimens, and since they afford some new information regarding the structure and relationship of such Crinoidal roots, description and discussion of them is here offered.

The specimens in hand are discoid or conical with flat base, or bent from that form when the surface to which the base had attached is not plane. They are found adhering to shells, Monticuliporoid stalks, Crinoid stems and especially to pebbles. They consist of polygonal calcite plates in the manner of Echinoderms in general. The center or apex of the cone bears a scar with central perforation. This scar is like those which are characteristic of Crinoidal roots and shows where a Crinoidal stem has been detached. In a few cases an attached stem fragment remains.

Among the specimens several species are represented, ranging in structure from those similar to the well-known *Lichenocrinus* on the one hand, and on the other to forms with lobate basal margin which link rather to the well-known and common form of roots with long, round cirri. Others tend to become globular and a relation to the problematical *Camarocrinus* is therefore to be considered.

[1] *The North American Crinoidea Camarata*, p. 49–51, 1897.
[2] *Geological Magazine*, Vol. V, p. 328, 1898.

PREVIOUSLY DESCRIBED FORMS

A few primitive Crinoidal bases have been heretofore described. James Hall noticed specimens from Trenton Falls in the Trenton limestone.[1] A drawing after Hall's figure *2a*, is reproduced here in Fig. 1. p. 243. His description of this and others merely states that they are "bases of attachment" "of the columns of some (uncertain) species of Crinoidea." Again James Hall described[2] specimens as occurring in the Niagara limestone, which may perhaps be well considered in this connection. One, represented by his Fig. 11, is described as "a fragment of a root with few radicles, ... showing a hexagonal canal," and the other, Fig. 10, is described as "a fragment of a root with numerous radicles." Those Figs. 11 and 10 are here represented by Figs. 2 and 3 respectively, by which their general character can be seen. Bather[3] calls attention to others which James Hall had described, in *Pal. N. Y.*, Vol. III, 1859, as *Aspidocrinus*, and of which Hall distinguishes three species, all from the Lower Helderberg, describing them on pp. 122–23, and giving figures of them, Plate V, Figs. 13–20. Hall appears much in doubt about their structure and relations. Neither his descriptions nor his figures are in any respect satisfactory. The fossils may, I think, rather be columnals, than bases.

From the Trenton limestone at Ottawa, Canada, Billings reports[4] certain specimens which should be noted. One specimen, represented in Fig. 1*g*, Plate V, *loc. cit.*, he says is "the base of the column" of *cleiocrinus regius* Bill. This specimen is not further described nor details of the root's structure shown. One may, however, infer that it is similar to that of the fragmental columns upon which he bases the species, *C. grandis* Bill.,[5] and of which he says, "The radix or base of attachment of the column consists of a number of large roots which appear to be composed of small polygonal plates." The figure of this one shows no more than the meager description gives,

[1] *Pal. N. Y.*, Vol. I, p. 86, Pl. XXIX, Fig. 2 *a*, *b*, 1847.

[2] *Pal. N. Y.*, Vol. II, p. 231, Pl. XLV, Figs. 10, 11.

[3] *Loc. cit.*

[4] *Canadian Organic Remains*, Decade 4, 1859.

[5] *Loc. cit.*, p. 54, Pl. V, Fig. 2*a*.

except that the column and root appear sharply defined at their junction.

In a little later publication,[1] James Hall presents conclusive evidence of a fragment of Crinoidal stem attached to a discoid base. The stem and therefore the base is identified as belonging to a particular species of Crinoidea, i. e., *Calceocrinus* (*Cheirocrinus*) *clarus* (Hall). These fossils come from the Silurian Niagara group. The base is similar to Fig. 1 and Figs. 6 and 7. Another base to which a fragment of stem remains attached is described from the Ordovician in the upper part of the Cincinnati group, at Cincinnati, Ohio, by F. B. Meek.[2] He says that it probably belongs to *Anomalocrinus incurvus* M. & W. It "consists of a solid expansion near an inch in diameter, with irregular margins." "It has a short piece of the column attached, which rises abruptly from the expansion, and is composed of very thin anchylosed segments, showing the appearance of being each made up of numerous little pieces, ... " i. e., like stems of *A. incurvus* M. & W. Fig. 4 and 5 here are drawn after his figures 6 *d*, *c*.

Wachsmuth and Springer,[3] say that "in the Hudson River group of Cincinnati, we occasionally find Crinoidal disks attached to pieces of coral, which closely resemble the dorso-central of *Antedon*. These disks have a pit or depression at the middle of the upper face, sometimes inclosing a small stem joint. They are irregularly round, and some of them have small processes passing outward from the sides which seem to represent primitive cirri (Plate I, Figs. 9, 10)." Drawings after their Figs. 9, 10, are given here in Figs. 6, 7. Opposite Plate I, in the description to Figs. 9, 10, they say "dorso-central plates, supposed to belong to a species of *Heterocrinus*." Wachsmuth and Springer consider the roots as having separated from the stem during the life of the Crinoid.

In a former paper on "A New Cystocrinoidean Species from the Ordovician,"[4] I have described a few specimens of discoid roots which were found associated with *Strophocrinus dicyclicus* Sar.,

[1] *Fifteenth Rep. N. Y. State. Cab. Nat. Hist.*, Pl. I, Figs. 17, 18, 1862.

[2] *Geol. Sur. Ohio*, Vol. I, "Paleontology," p. 18, Pl. II, Fig. 6, *d*, *e*, 1873.

[3] *Op. cit.*, p. 49.

[4] *American Geologist*, Vol. XXIV, pp. 263–76, 1899.

and which probably belong to that species. Three figures published[1] are reproduced here as Figs. 8, 9, 10.

Associated with discoid Crinoidal roots, in the Ordovician are the similar fossils known as *Lichenocrinus*. Several species of these have been described with such thoroughness, especially by Meek,[2] and with such citations as to make a review of the genus here seem unnecessary. The crateriform bases of these fossils are known to bear a slender stalk of polygonal plates in some cases. Yet this stalk is not known to have been identified, with certainty, as a Crinoidal structure. *Lichenocrinus* can be treated only as a problematic structure, notwithstanding concise knowledge of the fossils as they occur, and it may therefore be quite neglected here. In a large number of specimens of it which I have collected, nothing new has appeared. In regard to the discoid Crinoidal roots on the contrary, their structure has not been thoroughly described and they invite further study n this respect, as well as identification with recognized species of Crinoidea.

NEW DESCRIPTIONS

In order to facilitate scientific description a generic name is used here to include several taxonomic species of Crinoidal roots. This generic name, as in case of *Lichenocrinus* and of *Camarocrinus*, is not expected to coincide with any one generic term based upon described crowns and will be superseded by such generic terms as often as root structures are identified specifically with previously described crowns.

PODOLITHUS n. gen.

Primitive discoid or conical Crinoidal root-structures with more or less lobate margins and with a fixing-plate. Region about the stem-scar not depressed. Type *Podolithus schizocrinus*, n. sp., Fig. 11.

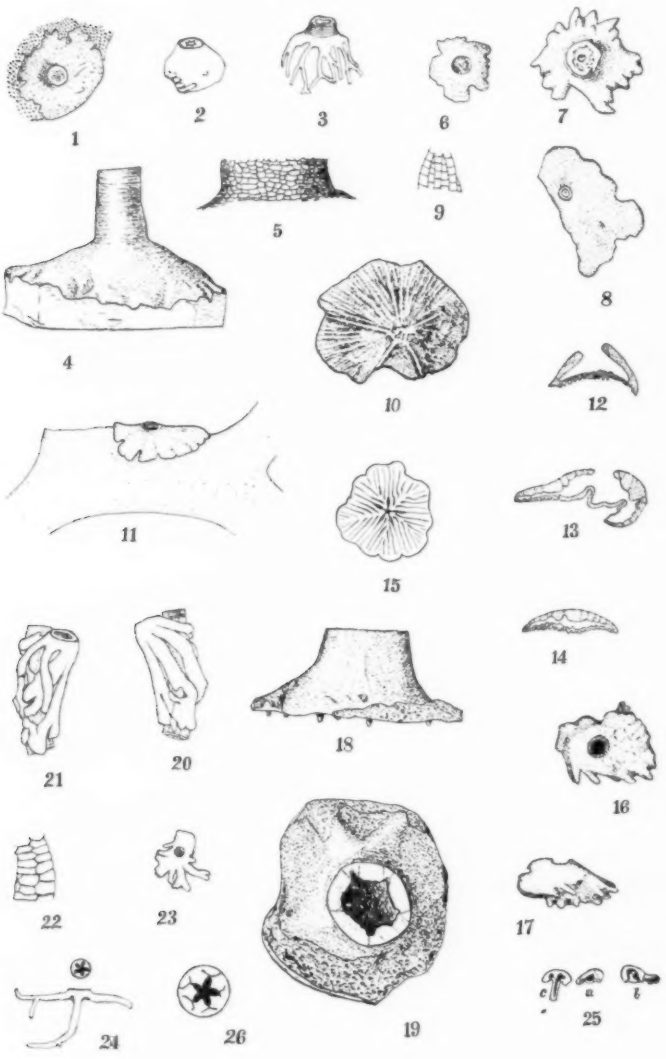
Podolithus strophocrinus nom. nov.

(Figs. 8, 9, 10)

To this type belong stem-bases which are low, conical, 1 to 5^{cm} in diameter, with nearly entire margin and generally circular outline, although by accident sometimes quite irregular. Fig. 8 shows the most unsymmetrical specimen found, while Fig. 10 represents one

[1] *Op. cit.*, Pl. XII, Figs. 14, 15, 16. [2] *Op. cit.*, pp. 44–52.

FIGS. 1–26



which although circular, appears not to be so because the margin is bent under. In the fossils, the stem is wanting, but from the scar it is seen to have been slender. The upper surface is smooth when well preserved. Suture lines show indistinctly that there are quadrangular plates, generally in rows, Fig. 9, arranged radially. Five rows of plates radiate from the center and between these other rows gradually intercalate. The interior is separated into canal-like spaces by partitions which appear to be inward thickenings of the plates, traversing the same along the rows radially. This structure has been seen by means of macerated and weathered specimens only, as is shown in Fig. 10, and the extension downward of the partitions is not exactly determined; but these probably touch the ground layer or fixing plate.

This type of Crinoidal root is remarkable for its large radius, small height, and relatively small stem-scar. A number of specimens were found at a particular part of a quarry where plates of *Strophocrinus* were abundant, and they are all believed to be structures of one species, i. e., *Podolithus strophocrinus = Strophocrinus dicyclicus*. These bases and the plates of *Strophocrinus* are otherwise rare. Their occurrence is in association with intra-formational conglomerate at the top of zone No. 4 (Stictopora bed) and in zone No. 5 (Fucoid bed) of the Galena-Trenton stage, at St. Paul, Minn. In view of their large size and close association with crown plates, it appears to be most probable that the bases were permanent anchors.

Podolithus schizocrinus n. sp.

(Figs. 11–17)

This species includes stem-bases which are from 3^{mm} to 2^{cm} in diameter, about one-fourth as high as wide, and in general outline conical but with thick and irregularly lobed margin (Fig. 11). The apex of one small specimen shows a flat circular stem-scar, with a star-shaped lumen, while others seem to have been either excessively macerated or reabsorbed in this part. Generally there is a circle of small pores or canal ends seen just within the rim of the central opening. No other openings through the wall appear anywhere. The top surface is dense and smooth with indistinct sutures. Transverse thin-section reveals, under the petrographic microscope, that

the top consists of calcite plates, increasingly numerous in larger specimens (Figs. 12 and 13). The plates are hexagonal to quadrangular, and arranged radially in short intercalating rows. The inner part of the plates appears in thin-section less dense than the outer, and is rough surfaced. Radiating ridges are also evident (Fig. 14), on the inside. Maceration may have reduced them, but they are not now seen to touch the fixing plate.

The fixing plate is thin and closely knit to the surface of support. It is a single large plate, united by suture only around the periphery of the root. On the upper surface of the fixing plate there are raised lines or ridges. These are well seen in one specimen from which the top plates are partly broken off, and in several others which have been weathered. None are complete, and a diagram (Fig. 15), is given, for the sake of completeness and clearness also, instead of a drawing of a single specimen. There is a central sharp elevation, from which radiate five angular ridges, and these are widest and highest at a short distance from the center. Other ridges intercalate, chiefly in diverging pairs, and all diminish in intensity toward the periphery.

The internal structure might be quite geometrically symmetrical if the external form were so, but in every specimen the place of growth has modified the form of the root more or less. The fixing-plate follows closely the surface of support, whose irregularities are reflected within. Again, some specimens have the stem-scar near or at one side, and directed obliquely to that side as if the surface of support had been vertical or inclined, the stem too having been vertical. In those cases the longer side is in every way the more developed. Figure 13 shows a root which had grown over the edge of the supporting object.

Figs. 16 and 17 represent a specimen which has grown on a slender branch of *Pachydictya acuta* Hall and surrounded it, the fixing-plate thence having bedded to an irregular, probably muddy, surface. The marginal lobes are extended as round short roots. Two of these, which are cleaved off, show central circular canals. One other specimen which was found near this one has grown in a similar way but has flat areas around the top.

This type of discoid base I find in greater numbers and through

greater range and wider distribution than any other. At Minneapolis and St. Paul it has been found in the Galena-Trenton in zone No. 4. (Stictopora bed) (Figs. 11, 12, and 15), in zone No. 5. (Fucoid bed) (Figs. 13, 14), and in zone No. 6. (Orthisina bed), and at Kenyon, Minn., also in zone No. 6 (Figs. 16, 17). Those from the Trenton of New York, as described by Hall (see Fig. 1), may belong to the same. In their occurrence they are associated with stems and crowns of *Schizocrinus*, to which they may belong. No other Crinoidal stems and plates are as abundant and no others are known in each bed. From the reabsorbed appearance of the stem-scar, as compared with other parts of the root in all sizes of specimens, I am led to adopt further the interpretation that the stems were loosed from the root at any convenient time during the animal's life.

Podolithus Anomalocrinus n. sp.

(Figs. 18, 19)

This species is known by a single specimen from zone No. 6 (Orthisina bed) of the Galena-Trenton, below Mantorville, Dodge Co., Minn. The specimen is a root with a fragment of a large stem with large lumen. From the stem to the margin its top surface is concave. The specimen is now free, although the fixing-plate on its under side bears a distinct impression from a former attachment upon a nearly flat surface. This impression shows quadrangular figures in transverse rows, and appears to be that of the inside of a *Receptaculites*. Short blunt processes occur at the angles where canals would run through that wall of *Receptaculites*. This impression indicates, I think, that the root grew on an intra-formational conglomerate pebble, which consisted of a fossil *Receptaculites*. Such fossils with more or less of adhering matrix are not uncommon as pebbles in that zone.

The margin of the root forms a sharp, slightly serrate edge in one place (left side of Fig. 19); in another it is abruptly turned upward, right side, and for the rest it appears to be overturned upon the top surface. The overturned part has a spongy-looking surface. Evidently the root was accidentally restricted in its growth. If it had not been, then the specimen would have resembled more closely the one described by Meek (see Fig. 4). The margin would have probably been five-lobed, corresponding to five prominences which radiate

from the rounded angles of the stem. As the specimen is, there appear distinct depressions of the top surface between the radial prominences where not covered by the overturned margin.

The stem's surface is marked by slightly raised transverse ridges, and a little weathering has brought intermediate rows of small pores to view. The exposed end of the stem shows numerous fine radiating anastomosing furrows, and a few larger ones. These were evidently canals between segments of the unbroken stem and the pores on the outer surface are obviously the ends of the same. The pores are united superficially by suture-like lines which give the stem the appearance of consisting of small plates. Meek describes a very similar structure in his specimen (see Fig. 5.). At each angle of the stem is a coarse suture. By observing these described marks, it is seen that the stem on my specimen extends down 5^{mm} from the top, and consists of about eight circles of thin undulating plates, which alternate in five vertical rows.

The surface below the stem shows faint close sutures, indicating that the top of the root proper is made up of numerous polygonal distributed plates.

Podolithus eucheirocrinus n. sp.

(Figs. 20–23)

This species includes bases, the conical form of which is concealed more or less by long root-like lobes of the margin. The largest specimen is grown around a Crinoid stem so that the lobes or radicles extend across one another (Figs. 20, 21). One small specimen has grown obliquely on a curved surface and has the lobes at the sides and lower margin only well extended (Fig. 23). The top or outer surface is dense, and consists of polygonal plates, though the sutures are in part indistinct. About the stem-scar the plates appear subhexagonal, alternating in radial rows, while on the lobes or radicles and their branches, the plates are transversely elongated and alternate in two rows (Fig. 22). The radicles are flattened on top but convexed on the sides.

The stem-scar is obscured on each specimen, and no stem fragment being attached, identification of these roots with any columns is uncertain. They are associated with Crinoid columns like the one upon which a root has grown (Fig. 20), which has five rows of colum-

nals, nearly corresponding in circles. They are found in the upper part of zone No. 4 (Stictopora bed), where specimens figured were found, and in the base of zone No. 5 (Fucoid bed) of the Galena-Trenton stage at St. Paul, Minn. The only probable related calyx is that of *Eucheirocrinus punctatus* (Ulr.) which has the same range, and although pieces of stem one-half inch long attached to them have oval rings yet, in view of the great differences known to mark Crinoidal columns, the lower part of the same might be the one under consideration.

Podolithus dendrocrinus n. sp.

(Figs. 24, 25, 26)

This species comprises roots in which the discoid or conical form is concealed, but in which the structure remains. They occur attached to hard surfaces with one to five simple or branched radicles of various lengths. Fig. 24 is of the largest specimen. One of its radicles curves downward. The radicles or lobes are smooth and quite round, excepting the under side by which they are attached. Seen from the upper side they consist of narrow transverse rings, but a thin-section shows that these are interrupted by the fixing-plate which unites with them by suture. Fig. 25 shows the thin-section ×4. The section is cut across three lobes, *a*, *b*, *c*, each of which attaches to the same Monticuliporoid stock. Fig. *a* cuts obliquely, striking two plates above, while *b* cuts a bifurcation. The fixing-plate in *c* penetrates a cell of the Monticuliporoid at that point. Compare Fig. 18. The lumen is represented in black.

The stem-scar is preserved in several cases and clearly shows a stellate lumen and radiate ligamental scars. Certain cylindrical Crinoid columns are found in the same strata and are easily matched with these though generally larger in size. Fig. 26 represents the end of such a column ×2 without the radiating striae, about 75 in number, which are omitted. It shows the lumen and ten distinct canals which run in the joint and in part thence through the segment. On the outer surface, the canals appear as distributed pores. The same canals are seen at the stem-scar of the roots, but I cannot find them lower on the disk or its lobes.

These roots and columns occur rarely in zones Nos. 4, 5, and 6, of the Galena-Trenton stage. Figs. 24, 25, 26, are of specimens

from zone No. 5, at St. Paul, Minn. An associated species of *Dendrocrinus* was the probable possessor of them.

DISCUSSION

In collecting specimens, I have not only obtained well-preserved materials for the study of structures, but have tried also to find means for identification of them. A root with entire column and crown has not been found, and should scarcely be expected to occur where all Echinodermal remains were badly scattered. But, roots and associated stems can be matched with crowns more or less successfully and careful effort to do this has been made.

From the evidence which is afforded by the described specimens, it may safely be concluded that these discoid stem-bases belong to Crinoidea, and admitting circumstantial evidence, the conclusion is imminent that they also belong to a diversity of Crinoidea. *Calceocrinus*, *Eucheirocrinus*, *Heterocrinus*, and *Anomalocrinus* belong to Bather's Order, Monocyclica Inadunata; *Schizocrinus* to Order, Monocyclica Camerata; *Dendrocrinus* and *Strophocrinus* to Order, Dicyclica Inadunata. To the circumstantial evidence may be added the fact that certain Cystidea have similar structures, the fixing-plate in *Lepidodiscus*, which I have collected here, being very like those of the Crinoidal discoid bases. This tends to prove that this structure is primitive and might persist in diverse lines of Crinoidal evolution.

As to structure, there is conclusive evidence that the fixing-plate in *Podolithus* is a single piece, while the top of the root is perhaps always of many plates. If I understand rightly, Wachsmuth and Springer[1] considered the entire root or discoid base as a single plate and compared it to the "dorso-central" plate of *Antedon*. Whether the fixing-plate or the entire root should be now called dorso-central, or perhaps neither comparison be made, I am not able to decide. Again the interior presents always, as far as known, raised radiating structures upon the fixing-plate and under the top plates, resembling *Lichenocrinus* in the latter. Also as in *Lichenocrinus*, no pores or canals to the exterior are seen aside from the stem-lumen and scar, even though attached columnals present external pores. Accidental

[1] *Op. cit.*

penetration of foreign substances into the root are probably always walled off from the internal cavity.

The described new species of *Podolithus* with species of *Lichenocrinus* include all the Crinoidal roots which are known to me to occur in the Galena-Trenton stage. Together they form a series which may illustrate the early evolution of Crinoidal roots from a primitive conical expansion of distributed polygonal plates, over a large circular fixing-plate, to a lobate form with plates in single rows over a deeply cut fixing-plate. Further reduction of the fixing-plate could produce the commonly known cirri with circular, perforated segments.

COMPARISON WITH *Camarocrinus*

At first sight, the discoid roots appear to differ greatly from *Camarocrinus*, but upon close comparison they are much more alike, the latter being a modified form of the former. Before trying to show this, the problem concerning *Camarocrinus* alone requires attention. That problem appears in the recently published work *On Siluric and Devonic Cystidea and Camarocrinus*, by Charles Schuchert.[1] In this work *Camarocrinus* is discussed in regard to history of the genus, mode of occurrence of fossil specimens, their structures and possible relationships. The discussion appears to be quite exhaustive and the description of the fossils, very thorough. The work is based upon a wealth of best materials of all three known species,[2] two of which Schuchert redescribes and one of which he presents as new. I may say further that nothing new or not described by Schuchert was found by me in materials which were obtained through the kindness of Mr. Schuchert and of Mr. Bassler of the U. S. National Museum. Following his thorough discussion Schuchert says in the summary:[3] "The writer realizes that the last word has not been said in regard to *Camarocrinus*, and the present work is offered with the hope that some paleontologists will attack the problem from another point of view."

Schuchert's statement just quoted follows paragraphs in which the belief is expressed, following the opinion of James Hall and other

[1] "Smithsonian Miscellaneous Collections," Vol. XLVII, Part 2, 1904.

[2] A fourth species, *C. asiaticus* Reed, has been later described. See *Paleontologia Indica*, New Series Vol. II, Memoir No. 3, 1906, p. 88.

[3] *Op. cit.*, p. 269.

authors, that the *Camarocrinus* structures were roots of Crinoids, serving as floats, from which the stems had parted before their sinking to place of rest. Bather[1] had stated a little more in particular, and Schuchert quotes him as saying of these fossils, that, "another curious modification, perhaps connected with a free-floating existence, was presented by the root of *Scyphocrinus* [=*Lobolithus*=*Camarocrinus*]." Schuchert's discussion, as I read it, throws a shadow over the grounds upon which Bather may have based his belief concerning *Scyphocrinus*, and tends to leave the fossil *Camarocrinus* as problematic as when James Hall first described it.[2]

Authorities agree, in short, upon these peculiar balloon-shaped fossils being the modified root-structures of some Crinoid or other. It may also be taken as evident that they floated. The unsolved problem concerns their origin, the interpretation of their structural parts, and their relation to any particular species of Crinoids.

Camarocrinus appears not to have been considered from the side of the known Crinoidal discoid roots. The nearest approach to such a point of view is the suggestion which will be here quoted about *Lichenocrinus* and in which Schuchert makes really no progress toward the solution of the problem. "*Lichenocrinus* represents the nearest approach of a modified Crinoid root to *Camarocrinus*. It, too, is camerate, the radiating striae seen on weathered examples being vertical plates extending upward from the attached base to the inner side of the surface plates."[3] Again, p. 269, "this form when compared with *Camarocrinus* is wholly different, as the base of *Lichenocrinus* is attached to foreign bodies. . . . ." Bather, too, cites *Lichenocrinus* as a Crinoid root[4] yet it is quite as problematic as *Camarocrinus*. Moreover, the comparison of the camarae of *Camarocrinus* with the camerate structure of *Lichenocrinus*, as just quoted, is not the right view, as I shall endeavor to show.

To explain the origin and homologies of *Camarocrinus*, I wish rather to compare it with such discoid roots as are here described, e. g.,

[1] *Treatise on Zoölogy*, Vol. III, "Echinoderma," p. 135 (1900).

[2] More recently, Butler has found further evidence in support of his view, in the association of *Scyphocrinus* and *Lobolithus* remains in Silurian rocks of Cornwall. See Transactions of the Royal Geological Society of Cornwall, Vol. XIII, Part III, pp. 191–97, 1907.

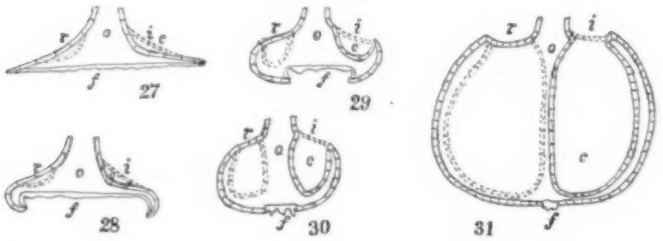
[3] *Op. cit.*, p. 268.

[4] *Op. cit.* p. 133.

Figs. 11, 13, 17, and 18. These bases are evidently very plastic to environmental conditions and certain characters in them if increased under exceptional conditions might well have changed to such as *Camarocrinus* possesses. Those characters are the occasionally turned-under margin (Fig. 13), and the five or more depressed spaces of the top surface (Fig. 19). These depressions may be termed inter-radicle pockets, since they lie between the main canals and lobes which radiate from the corners of the stem and lumen, or between branches of the same, all of which may be termed radicles.

A series of diagrams are given here to help show the probable origin of *Camarocrinus* (Fig. 31) from a discoid root (Fig. 27).

FIGS. 27–31



Taking the pentameral symmetry as typical, then a vertical section passing through a radicle, *r*, on one side, would cut the inter-radicle *i* on the other side. The respective inter-radicle and radicle contours, not cut by the plane of the section, are drawn in broken lines. Since *Camarocrinus* is supposed to have floated in inverted position, it should be represented so, except that comparison is easier when all figures correspond. Fig. 27 represents a known discoid base with normal, wide fixing-plate, *f*, and shallow, inter-radial pockets, *c*. Fig. 28 represents it with the margin turned under because of limited ground. Fig. 29 is an hypothetical representation of the same attached to a floating object by still more limited area, so that a smaller fixing-plate, *f*, and deeper pockets, *c*, result. Fig. 30 represents an adaptation where the supporting object and fixing-plate are less in surface and the pockets—gas filled—are enlarged. Fig. 31 represents *Camarocrinus* with fixing-plate, *f*, very small, not larger than other plates, while the pockets, *c*, are correspondingly enlarged and approximated.

The pockets or camarae of *Camarocrinus* are not internal divisions but invaginations of the outer wall, hence communicating not with the interior but the exterior. The internal partitions of *Podolithus* and of *Lichenocrinus*, too, correspond not with its "camarae" but with the canals of the interior, Fig. 27, and with partitions of the medio-basal chamber *o*, Fig. 31, and of other interspaces of the closely folded "double" wall. *Camarocrinus* is not to be considered as "double walled" but single walled. The wall, folded upon itself is united "by many short, stout, blunt processes,"[1] and these processes may be considered as homologous with the internal partitions of *Podolithus* and of *Lichenocrinus*. The inner surface of the wall of *Camarocrinus* is in fact marked by knoblike extensions, especially of the larger of the plates, and by pore-like enlargements of the sutures. Maceration and weathering must tend to open these latter, one after another, to the exterior. I am in doubt, therefore, whether the pores through the walls which Schuchert so clearly represents,[2] were originally open to the exterior or not. Presuming that they were, their nature may be the same as the pores on the column, though not seen on the base of *Podolithus anomalocrinus*. I have not discovered in the specimens of *Camarocrinus* the particular plate which is the original fixing-plate, but it might be seen on favorably young specimens.

Excepting possibly the supposed pores, the structures of *Camarocrinus* are those of *Podolithus*. Further, the observation may be made, that since *Schizocrinus* Hall and *Scyphocrinus* Zenker belong to the same family, *Glyptocrinidae* according to Bather, the probability that *Podolithus schizocrinus* belongs to the one, gives greater weight to the contention that *Camarocrinus* in part, at least, belongs to the other.

EXPLANATION OF FIGURES

Fig. 1.—Base of a Crinoidal column, on a coral, from the Trenton limestone; after Hall.

Figs. 2, 3.—Crinoidal roots from the Niagara limestone; after Hall.

Figs. 4, 5.—Root with fragment of column, from shales of the Cincinnati stage, and part of column of same, magnified; after Meek.

Figs. 6, 7.—Roots or "dorso-central plates," from shales of the Cincinnati stage; after Wachsmuth and Springer.

[1] Schuchert *op. cit.*, p. 263. [2] *Op. cit.*, Pl. XL, Figs. 8 10.

Figs. 8, 9, 10.—*Podolithus dicyclicus* nom. nov., from the Galena stage. Fig. 8, a well-preserved but unsymmetrical root; Fig. 9. part of surface of the same ×2; Fig. 10, a weathered specimen.

Figs. 11–17.—*Podolithus schizocrinus* n. sp., from the Galena stage. Fig. 11, a small root on a coral ×2; Fig. 12, vertical section of a similar one ×2; Fig. 13, vertical median section ×2, of a specimen which has overlapped the supporting coral; Fig. 14, section of same ×2, not median; Fig. 15, diagram of upper surface of fixing-plate with ridges; Figs. 16, 17, top and side views of a large specimen which has surrounded its attachment.

Figs. 18, 19.—*Podolithus anomalocrinus* n. sp. Side and top view of root and part of column; from the Galena stage.

Figs. 20–23.—*Podolithus eucheirocrinus* n. sp., from the Galena stage. Figs. 20, 21, views of a large lobate root surrounding a Crinoidal column; Fig. 22, part of surface of same ×2; Fig. 23 a small specimen.

Figs. 24, 25.—*Podolithus dendrocrinus* n. sp., from the Galena stage. Fig. 24, side view of root with long rounded lobes, and of stem-scar of same; Fig. 25, section ×4, across three lobes, *a*, *b*, *c*, of another specimen.

Fig. 26.—End of a round column ×2, showing lumen and canals; corresponding to Fig. 24.

Figs. 27–31.—Diagrammatic sections, Fig. 27, of *Podolithus*; Fig. 28 of same with margins turned under; Figs. 29, 30, hypothetical modifications; Fig. 31, of *Camarocrinus; f*, fixing plate; *o*, "medio-basal" cavity; *r*, radicle; *i*, interradicle contours; *c*, pockets or camerae.

STUDIES FOR STUDENTS

RELATIONS BETWEEN CLIMATE AND TERRESTRIAL DEPOSITS—*Continued*

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PART II. RELATION OF SEDIMENTS TO REGIONS OF DEPOSITION

INTRODUCTION

Upon a comparison of the character of the deposits laid down upon the topographically somewhat similar surfaces of large deltas but

under the most unlike conditions of temperature and rainfall, such, for instance, as the deposits upon the deltas of the Indus, the Amazon, and the Yukon, it is perceived that the climatic conditions existing over the surface of deposition form a factor of primary importance in governing the nature of fluvial and pluvial deposits. A proper interpretation of ancient continental sediments cannot be made, therefore, if the climatic factor be neglected, and on the other hand the deposits of ancient delta surfaces should contain a more or less accurate record of the climatic conditions of origin. But a closer inspection of modern deltas shows that different parts of the same delta surface exhibit markedly different conditions of deposition owing to the somewhat varying local geographic features, such as lakes, swamps, and natural levees, which may exist. In desert regions, as exemplified by the delta of the Helmund, the great internal river of Persia, portions not now used by the river are barren sandy deserts subjected to deep wind scour, occasionally in this instance exposing ancient ruins, and the corresponding heaping-up of aeolian deposits, while at the same time such shifting, shallow, and variable lakes as that of Seistan, the reservoir into which the Helmund drains, are giving rise to interstratified, truly lacustrine deposits.[1]

Therefore in the climatic interpretation of ancient continental deposits proper allowance must first be made for the geographic variations which occur within the region of deposition. The field studies must be sufficiently broad to lead to some recognition of the ancient geography before the ancient climate may be determined. To that end the modifications in deposit due to the influence of the local geographic conditions will first be discussed.

Influence of Nature of Surface of Deposition

Piedmont Slopes—Aerial Deltas

These are more usually formed in arid or sub-arid climates, since in such the river waters progressively escape, after leaving the mountains, into the thirsty soil and air. The overloaded stream consequently throws down its burden of waste upon a slope which may vary from 100 feet per mile in the case of the coarser and steeper fans

[1] Col. Sir Henry McMahon, "Recent Survey and Exploration in Seistan," *The Geographical Journal of London*, Vol. XXVIII, 1906, pp. 209–228.

to those which may be as low in grade as five or ten feet per mile. The latter are built by the more slowly diminishing volume of the larger streams, and their sands or silts, when properly irrigated, form soils of the greatest richness. As an instance of the physical conditions which may exist upon such subaerial delta fans there may be quoted the following description by Davis of the plains of the rivers which flow north from the mountains of northern Afghanistan into the Kara Kum desert:

> The surface was absolutely plain to the eye, except for the dunes, and the dunes departed from the plain only as wind waves at sea depart from a calm surface. Although apparently level the plain has slope enough to give the Tejen, the Murg-ab, and the Amu rapid currents, in which these rivers carry forward a great volume of mountain waste. We were fortunate enough to see the Tejen and the Murg-ab in flood. The former had overflowed its channel and spread in a thin sheet for miles over the plain. The latter would have spread but for the restraint of dykes at Merv. Some of its waters had escaped farther upstream and came to the railroad, wandering across the plain among the dunes, a curious combination of too much and too little water supply.[1]

Following the inundation under natural conditions a temporary vegetation springs up, finally withering and giving place to the desert until the period of the next season of flood. Such districts of sedimentation give a maximum contrast of seasons of desert aridity alternating with periodic inundations; a contrast which is to be regarded as due not only to the arid climate but equally to the slope of the surface supplemented by the porous nature of the deposits, allowing of rapid drainage followed by a drying of the soil. In climates of a semi-arid character, as over the High Plains of the United States, the flood plains show a similarly well-drained character, the swampy areas being found more commonly among the dunes of the upland than over the river plain and due to aeolian more than to fluviatile action.[2] In wet climates the opportunity for deposition of waste upon such slopes is more rare and can occur in marked development only where streams in a highly loaded condition escape from lofty mountains. Such fans may be noted among the Alps with surfaces free from swampy areas, except, as in the case of the valley of the Upper Rhone, where

[1] W. M. Davis, *Explorations in Turkestan*, 1905, p 54, "Carnegie Institution Publications," No. 26.

[2] See the Brown's Creek and Camp Clarke, Nebraska, quadrangles, "Topographic Sheets," *U. S. Geological Survey*.

opposing fans dam up the line of confluent drainage. The final conclusion, therefore, is that over such piedmont slopes there is a great freedom from areas of swamp and the greatest opportunity for drying and aeration of the soil between the times of flood. Such deposits should normally show complete oxidation of the iron and a complete absence of carbon. In hot climates evaporation from the soil is very rapid and oxidation of the humus is also rapid, resulting in the red clays characteristic of the moist tropical climates. Even the short intervals between rains which occur in the most pluvial of tropical regions are sufficient, therefore, to bring about the oxidation of the iron and elimination of the carbon from all but permanently swampy areas, giving rise to the red muds of the Amazon and Congo rivers.

In cool climates, on the contrary, evaporation and oxidation are both diminished in intensity with the result that carbon may accumulate upon slopes to an extent impossible in warmer climates, giving rise upon consolidation to carbonaceous sandstones or even conglomerates. The existence of the latter chemical conditions, leading to the accumulation of carbon even upon sloping surfaces, is found only in climates which approach a continuously rainy character and possess in addition cool summers. As an example, such climatic conditions are found at present upon the western slopes of Ireland, though the accumulating piedmont slopes are there wanting. Peat swamps, however, are observed to exist upon hilltops, slopes, and valley bottoms, covering one-seventh of the entire island. Many bogs possess a grade sufficient so that in times of excessive rain they may swell and burst and disastrously flood the lower valleys. Less familiar but still better examples are offered by the cool and humid maritime mountain slopes of Alaska. Of these Russell states:

> About the shores of Unalaska and for fully 2,000 feet up its rugged mountain slopes the vegetation is essentially the same as at St. Michaels upon the Yukon delta. In climbing the steep slopes about Iliuliuk I often had great assistance from the dense mat of vegetation two or three feet thick, which, clinging to the rocks, converts their angular crags and shattered crests into smooth domes of soft, yielding moss. On the steep slopes, as in the swamps, the vegetation is always water soaked, owing to the extreme humidity of the climate in which it thrives. Lakelets are common on slopes and hillsides that would be well drained were it not for the spongy nature of their mossy banks.[1]

[1] "Notes on the Surface Geology of Alaska," *Bulletin of the Geological Society of America*, Vol. I, 1890, pp. 125, 126.

Turning to the past for illustrations of these conclusions, we may point out that the coarse, coal-measure conglomerates of the Narragansett Basin and the less coarse, but still conspicuous, Triassic conglomerates of the Connecticut Valley, both give evidence of rather local derivation and of continental deposition, evidence which cannot, however, as previously stated, be here discussed in detail. The local origin and coarse texture indicate deposition upon slopes of at least from five to ten feet per mile and possibly much greater, sufficient, under the usual climatic conditions, for good drainage. The Triassic conglomerates of the Connecticut Valley show a large amount of fragmentary fresh feldspar, iron completely oxidized, and no trace of carbon, either in the matrix or associated red shales, the fish fossils being found in the rare black shale bands. The conglomerates of the Narragansett Basin, on the other hand, with the exception of the Wamsutta beds, show a bleached matrix containing more or less carbon and are associated with a great volume of highly carbonaceous shales.

From these facts alone, therefore, it would be judged that the Carboniferous conglomerates, granting their subaerial origin, were accumulated during a period of cool and more or less continuously rainy climate.

The Triassic conglomerates, on the other hand, are associated with many features of climatic significance which also cannot be taken up here in detail, but which independently indicate a semiarid climate with hot summers and possibly cold winters. The characteristics, therefore, of these conglomerates, originating from the same geologic province, but in climatically dissimilar geologic times, are such as to emphasize the importance of the present conclusions regarding climatic influences upon the deposits of piedmont slopes. Further discussion of this subject must be left for the section on climatic influences.

LOWER FLOOD PLAINS—AQUEOUS DELTAS

The slope of graded streams progressively diminishes from source to mouth, the larger and longer the stream the flatter the grade tending to become. The deltas of the larger rivers commonly possess a slope of less than a foot per mile, and on the seaward margin pass into practically level salt-water marshes, underlaid by heavy deposits of

flocculated clay, giving rise to conditions unfavorable for either underground or surface drainage. In the case of piedmont slopes it was seen that in desert climates the greatest seasonal contrasts exist between too much and too little water, but that all parts fare much alike and become dried out through the greater portion of the year. Over the lower flood plains, on the contrary, such striking contrasts of swamp and desert are permanent features through series of years. Using the delta of the Colorado River as an example of one developed under highly arid conditions, Macdougal describes in a recent work how:

> At places where the river is cutting into gravelly and sandy bluffs, within the compass of one hundred feet may be found the most vivid contrasts of rank swamp vegetation and water-loving plants having broad leaves and delicate tissues with the toughened spinose, and hairy xerophytic forms of the desert.
>
> The quantity of food furnished by the swampy jungles is sufficient to support a vast amount of native animal life, and furnishes inviting feeding-grounds for migrating birds. The countless millions of young willow and poplar shoots supply food for the beaver, which bids well to hold out long in the impassable bayous and swamps against its trapper foe.
>
> Nearer the gulf are found great sloughs, in which are extensive fields of the "wild rice," while the land subject to the action of the overflow of the tides supports a carpet of salt-grass.[1]

Similar areas of more or less permanent swamp, increasing toward the seaward margin, may be noted as characteristic of other large deltas, such as those of the Nile and the Indus, developed as with the Colorado in truly desert regions. In ancient river deposits, therefore, an appreciable proportion of paludal deposits must be expected to occur over the terminal portions of the delta under all climatic conditions, and such must be allowed for in making inferences in regard to the ancient climate. As means for separating these geographic and climatic factors, however, may be noted the close association over the desert delta of paludal and desert conditions and the much smaller proportion of swamp which is permanent than in the case of more pluvial climates. In the long seasons of dessication all but the lowest bottoms become dried out and mud-cracked.[2]

[1] "The Delta of the Rio Colorado," *Bulletin of the American Geographical Society*, January, 1906, pp. 4, 10, 11.

[2] D. T. Macdougal, *op. cit.*; see Fig. 1.

A number of conditions besides the climate will be found, however, to affect the ratio over the marginal portion of the delta, of swamp to the well drained areas. These may be enumerated as follows:

First, a slowly rising water level tends to flood the lower portion of a delta and bring large tracts into the condition of permanent swamps. As such movements of water level are variable and intermittent the extent and ratio of the seaward paludal deposits seen in cross-section in ancient deltas will vary through the section. Such, however, will be practically absent from the region of the apex of the delta, but will be marginal to, and most commonly underlie, marine strata marking invasions of the sea.

Second, the contest of two or more rivers in building up a common flood plain or delta results in the damming back of the weaker members of the system. The paludal regions tend to migrate away from the greater sources of sediment.

Third, the possession of a wide flood plain, as in the case of the lower Mississippi Valley, is liable to result in a considerable area of back swamp, there being less infilling from the sides, and the river with its natural levees occupying a lesser portion of the whole.

As factors tending on the contrary toward good drainage of the lower river plains may be mentioned: first, a stationary or even slowly subsiding water level; second, the possession of a flood plain by a single river such as the Nile as contrasted with the Euphrates-Tigris system of Mesopotamia; third, aggradation within a confined valley, exemplified by the Great Valley of California, where side wash is present to such an extent that the ground slopes gently but continuously from the hillsides to the trough of the valley.

ELIMINATION OF LOCAL GEOGRAPHIC FACTORS

The preceding discussion has dealt with the upper or lower flood plains of the river system as a whole and it has been seen that the character of the sediments deposited must be largely influenced by the physical conditions existing in the region of deposition, whether near the mountains as piedmont slopes, or at a distance as deltas built into shallow seas. Within the confines of the terminal deltas, however, there exists greater local diversity of conditions.

In the study of ancient deposits now exposed to view in scattered

and fragmentary sections such a comprehensive knowledge of the limits and surface nature of the original formation becomes, however, a difficult problem. Certain rules should, therefore, be formulated, by following which the local geographic conditions may be most largely eliminated from the problem of the climatic interpretation. Such rules may be stated as follows: First, the general direction of the former land on the one hand and of the sea on the other is ordinarily readily determinable. The deposit is coarsest, the slope of the river-plain steepest, the surface and underground drainage best, over those portions of the deposit nearest the source of sediment. The highest proportion of continental as opposed to marine strata will ordinarily be found in the same region. This, therefore, will be the most favorable place for the study of all but the chemical or organic deposits. Second, toward the landward or upstream side the thicknesses of the formation will commonly vary along successive outcrops. Such variable thicknesses may be due either to excessive subsidence causing drainage of the sediments *toward* and into the basin, filling it in; or excessive sedimentation building up piedmont slopes, the excess passing *outward* in other directions, or to a combination of both conditions. Observation of ancient geosynclines, such as that which faced Paleozoic Appalachia, shows that in many cases excessive sedimentation in the vicinity of some large river appears to be the more common and fundamental cause, the zone of maximum deposition being characterized at the same time by the coarsest material and a decreased proportion of chemical and organic deposits. In continental formations, therefore, the region of maximum thickness, as well as greatest coarseness, is usually the most favorable for the study of the mechanical conditions of deposition. Third, the regions of scanty sedimentation and the paludal zone facing the ancient water body are the most favorable for the development of chemical and organic deposits. Under arid climates will here be found beds of salt and gypsum intercalated with both continental and marine argillaceous strata, possibly associated with a small amount of variegated shales; but, judging from geological experience, never deposits of carbon. Under typically rainy climates, on the other hand, whatever occasional deposits of salt and gypsum may form are speedily washed away during a following season of rain, and the permanently

flooded condition of the swamp areas leads to the preservation of carbonaceous strata.

With the accentuation of climates toward aridity or toward a cool and continuously pluvial condition, these chemical and organic deposits, developed most typically on the distal margin of the delta, spread inland and become of greater geological importance, as illustrated by the brine pools of the desert delta of the Volga, on the one hand, or the impenetrable flooded jungles of the Amazonian silvas, on the other.

Climatic Influences in Regions of Deposition

The geographic and climatic influences in the regions of erosion produce two effects in the region of deposition. One, a chemical and mineralogical influence which becomes generalized and vague with prolonged transportation; the other through variations in erosion causing variations in the coarseness and quantity of waste, also becoming masked by the effects of long transportation. On piedmont slopes, therefore, being nearer the headwaters, the climatic conditions of erosion, of transportation, and of deposition all find obvious expression; but over the more distant parts of a river system the more conspicuous factors governing the nature of the sedimentation are the *variable nature of the transportation*, regulating the coarseness and quantity of the waste, and the *variable climatic conditions existing in the region of deposition*, largely governing the chemical and mineral nature of the deposit. The microscope and the chemical analysis will still, however, be able to trace underlying influences due to the nature of erosion, as indicated by existing deposits of loess in Mississippi and red laterite muds spread in places upon the bottoms of tropical seas.

In taking up in detail the present topic of the influence of climate in regions of deposition, the effects upon the deposits of four kinds of climates may be considered, namely, constantly rainy, intermittently rainy, subarid, and arid. The effects of increased cold, by preventing evaporation, produce results similar to an increased and more continuous rainfall. Cool summers rather than cold winters are more effective in this way and lead in northwestern Europe to the production of extensive peat deposits in regions which receive but twenty-five to

forty inches of rain per year, distributed, however, rather uniformly through the seasons. Where the cold is prolonged and intense, however, as found over the tundras within the Arctic Circle, a fifth class, that of the frigid climates, may be considered.

EFFECTS OF CONSTANTLY RAINY CLIMATES

Constantly rainy climates are defined by W. Köppen as those where no month has less than fifteen rainy days.[1] Such climates are dominant south of south lat. 45°, touching southwestern Patagonia, Tierra del Fuego, and southern New Zealand. Another large area exists in the North Atlantic, touching Iceland and approaching the shores of Ireland, Scotland, and Norway. Certain tropical areas also have nearly constantly rainy climates, at least six days in every month being rainy, the northern half of the basin of the Amazon being the most notable from the present point of view. In such regions the forest vegetation attains its maximum development, the cooler parts of the temperate zones hardly lagging behind the most favored tropics in luxuriance, provided that the winter winds are moist, the soil and antecedent vegetation have been spared by glaciation, and the more recent forests by man. On the southwestern side of Patagonia, for instance, in south lat. 55°, Hatcher speaks of a vegetation so profuse as to suggest that he had been transported into the midst of some tropical jungle.[2] Dusén states also that in the interior of Tierra del Fuego, near the harbor of Puerto Angosta, the typical virgin forest reminded him of the West African virgin forests which he had seen.[3]

In this connection the observations of Darwin upon the forests of Tierra del Fuego are significant. He mentions the thick bed of swampy peat covering the steep slopes above the timber line while of the almost impenetrable forest below he states:

> In the valleys it was scarcely possible to crawl along, they were so completely barricaded by great mouldering trunks, which had fallen down in every direction. When passing over these natural bridges, one's course was often arrested by sinking knee-deep into the rotten wood; at other times when attempting to lean against a firm tree, one was startled by finding a mass of decayed matter ready

[1] *Bartholomew's Physical Atlas*, Vol. III, 1899, Plate XIX.

[2] *Princeton Patagonia Expeditions*, Vol. I, 1903, p. 150.

[3] P. Dusén, "Ueber die Vegetation der feuerländischen Inselgruppe," *Englers Jahrbücher*, Band XXIV, 1898.

to fall at the slightest touch.[1] . . . . The entangled mass of the thriving and the fallen reminded me of the forests within the tropics—yet there was a difference: for in these still solitudes, death, instead of life, seemed the predominant spirit.[2]

These statements bring into prominence the slowness of organic decay in cool climates and its rapidity in warm, permitting the accumulation of dead vegetable matter in the one region, quickly removing it from view in the other. Schimper also calls attention to the relative poverty of humus in tropical soils and emphasizes the statement that peat is never produced in the tropics except on mountains over 1,200 meters in height.[3]

Influence of arctic climates.—Within the colder portions of the temperate zones a lesser rainfall and severer winters result in a somewhat diminished luxuriance of vegetation, but, as previously noted, on account of the less intense evaporation and oxidation notable deposits of carbon may still result. In the interior of Alaska the precipitation varies from about ten inches per year on the eastern boundary to about twenty-five inches per year where the interior province passes on the west into the relatively humid Behring Sea province. The heaviest precipitation is in summer, but is always moderate in amount.[4] Under these conditions of rainfall, which in a hotter climate would lead to aridity or semiaridity, there is here found on the lowlands, where these are within the timber line, a luxuriant forest of spruce and willow with an undergrowth of cryptogamic character.

Within the Arctic Circle beyond the limit of arboreal vegetation exist the vast treeless moss-covered plains known as the tundra, perpetually frozen below the depth of a foot or two. In the far north the tundra may be developed under a rainfall of not over ten inches per year, but in such regions the vegetation is meager and barely covers the soil. Farther south, however, and in more rainy districts a thick carpet of peaty vegetable matter may accumulate. A tundra of this character is found on the delta of the Yukon under a rainfall of from

[1] "Ascent of Mount Tarn," *The Voyage of the Beagle*, June, 1834.

[2] *Ibid.*, "Scenery of the Mountains and Retrospect."

[3] *Plant Geography*, 1898 (Eng. trans.), pp. 381, 382.

[4] Cleveland Abbe, Jr., "Climate of Alaska," pp. 147, 154–157, Professional Paper No. 45, *U. S. Geological Survey*, 1906.

eighteen inches at St. Michaels to thirty-three inches at Fort Alexander, the precipitation occurring largely as rain and from May to October.[1]

Russell, speaking of the tundra as developed upon the delta of the Yukon and the south, says:

General characters.—The tundra in typical localities is a swampy, moderately level country, covered with mosses, lichens, and a great number of small but exceedingly beautiful flowering plants, together with a few ferns. The soil beneath the luxuriant carpet of dense vegetation is a dark humus, and at a depth exceeding about a foot is always frozen. On its surface there are many lakelets and ponds surrounded by banks of moss even more luxuriant than on the general surface. It is not always a level plain, however, but is frequently undulating and may surround and completely cover hills of considerable elevation. The dense tundra vegetation also extends up the mountain side and occupies the entire region where the conditions are favorable for its formation. At the localities where I examined it the whole surface, excepting the faces of steep cliffs and the summits of high mountains, was covered with the same dense brown and green carpet. The characteristics are the abundance of mosses and lichens and the absence of trees. Cryptogamic plants make more than nine-tenths of its mass. On their power to grow above as they die and decay below depends the existence of the tundra.

The depth of the humus layer beneath the moss was found to be about two feet at St. Michaels. A mile east of the village it was about twelve feet. In the delta of the Yukon a depth of over fifteen feet was seen at one locality. As satisfactory sections are rare, these measurements do not indicate its average thickness. A depth of 150 to 300 feet has been assigned by several observers to the tundra where it is exposed in a sea cliff on Eschscholtz Bay, at the head of Kotzebue Sound.[2]

Chemical nature of deposits of constantly rainy climates.—The distinctive chemical effects are to be noted in the absence or small amount of the soluble elements, embracing iron, magnesia, lime, potash, and soda, and in contrast, the presence of carbon. Owing to the diminished evaporation and the constant saturation of the soil of the entire flood plain, aeration and oxidation of the soil is prevented while the decaying organic matter results in deoxidizing effects. Where the leaching and deoxidizing actions have fullest opportunities for work, as in the clay soils beneath swamps, all soluble plant food may be leached out. Where the chemical effects are less pronounced

[1] Cleveland Abbe, Jr., *op. cit.*, pp. 146, 152.

[2] I. C. Russell, "Notes on the Surface Geology of Alaska," *Bulletin of the Geological Society of America*, Vol. I, pp. 125–27.

the iron may be deoxidized and concentrated, but not eliminated. The colors of the deposits are consequently white or black or gray. These opposed relations of carbon and iron and the leaching of soluble components from the fire-clays underlying swamp deposits as derived from the study of modern instances are seen to correspond to the nature of the coal-measures and the conditions of moisture necessary for their formation have long been emphasized, but the added condition of coolness as favoring more extensive accumulations of carbonaceous character has not until within the past few years been generally recognized. The great influence of coolness was perhaps first pointed out by Russell, who in connection with the carbonaceous deposits of Alaska expresses the following opinion:

A possible origin of coal seams.—So vast is the amount of vegetable matter now imprisoned in the tundra of the North, that I venture to suggest that possibly some coal seams may have had a similar origin.

This suggestion does not seem so very unreasonable when one remembers that except in the circumpolar tundra, deposits of vegetable matter are nowhere accumulating at the present day to anything like the extent or thickness required for the formation of coal fields like the one, for example, of which Pennsylvania still retains a remnant. Botanists will say at once, in opposition to this suggestion, that the flora of most of our coal fields, and especially those of Paleozoic age, indicate tropical or sub-tropical conditions. The flora of the tundra, however, like the plants of the Carboniferous, is essentially and characteristically cryptogamic. Two species of Equisetum, which may be considered as representing the Calamites of former times, flourish with rank luxuriance over great areas along the Yukon.[1]

It is further desired at this place to call attention to the other chemical characters of the deposits, by which even without the presence of carbon the rainy nature of the climate may be inferred. Various investigators have shown that in those portions of tropical soils leached by heavy rainfall which are soluble in hydrochloric acid soda is quite absent, potash is low, the residual soils usually not possessing over 0.1 per cent.[2] of potash and the river alluvium not over 0.2 to 0.3 per cent.,[3] the leached alluvium of Assam, a region of extremely heavy rainfall, containing but about one-half the potash of the drier soils of the Indo-Gangetic plain. The same characteristics

[1] *Op. cit.*, pp. 127, 128.

[2] E. W. Hilgard, *Soils*, 1906, p. 355.

[3] *Op. cit.*, pp. 412, 413.

would be evident upon a complete analysis of the alluvium, but unfortunately for geological purposes such complete analyses of soils are seldom made. Lime exists in higher percentage in river alluvium than in upland soils, but Mann has shown that it is extremely deficient in the soils subjected to heavy rainfall, the general average in the Assam alluvium soluble in hydrochloric acid being about 0.08 per cent., as against nearly 1.0 per cent. in the average Indo-Gangetic soil.[1] It is noticeable that in the true tropical soils the content of magnesia is considerably above that of lime; a fact readily intelligible from the more ready solubility of lime in carbonated water.[2] That it is leached out also, however, is indicated by its content of 0.5 per cent. in the soluble portion of the Assam tea soils as contrasted with its presence to the extent of 1.3 per cent. in the soluble portion of the Indo-Gangetic alluvium.[3] The iron of the Assam soils is also low, but it is not deficient in tropical soils in general, giving on the contrary a characteristic red to such lands as Madagascar and Ceylon.

The continuously rainy climates may be divided into those situated in the equatorial belt, usually possessing at least short dry seasons, and those situated in the cooler parts of the temperate zones. The preceding discussion on the chemical distinctions has been largely based upon soils of the torrid zone or warm temperate, as in the case of the Assam alluvium. In the cold temperate regions recent glaciation has in many cases prevented the establishment of normal chemical relations between the rocks and the atmosphere, but such observations as have been made indicate, as was shown in Part I, that decomposition is greatly reduced. From the foregoing it may be concluded that the broad association of carbon with sediments which are thoroughly decomposed and leached throughout is the mark of continuously rainy climates which are tropic or at least warm temperate; with sediments imperfectly decomposed and incompletely leached the mark of more or less continuously rainy climates which are in addition cool or cold. The best microscopic test after the lithification of the alluvium may be the absence or presence of potash minerals. The carbonaceous shales of the anthracite coal-measures of Pennsylvania, except the fire clays immediately below the coal beds, possess a marked abundance of muscovite, indicating the presence of consider-

[1] Hilgard, *op. cit.*, p. 413. [2] *Op. cit.*, p. 405. [3] *Op. cit.*, p. 413.

able potash and magnesia. From this would be inferred an origin under cool climatic conditions, in line with the inference previously drawn from the Carboniferous conglomerates of Rhode Island—calling attention to the importance of microscopical or chemical examination and comparison of argillaceous sediments of similar continental but presumably of unlike climatic origin. In contrast with the muscovite shales of the coal-measures may be noted the absence of muscovite in the carbonaceous shales of the Hudson River and Hamilton periods which underlie the Carboniferous and have consequently been subjected to equal or even greater metamorphism. While these latter shales are of marine origin it is not clear that that fact alone could lead to this peculiar distinction.

That a cool climate, while undoubtedly favorable, is not necessary for the production of coal-measures is, however, shown at the present time by the swamps of the Amazon and, in the past, by the warm-temperate flora of the Eocene coals of the Pacific slope. The absence of frost rather than a hot climate is, however, all that is necessarily implied by the Eocene vegetation.

EFFECTS OF INTERMITTENTLY RAINY CLIMATES

Intermediate character of deposits.—Climates of this class are such as characterize those portions of the world where crops may be grown without the aid of irrigation, but where one or more months may be relatively free from rain. Under these familiar conditions the soil of the flood plains normally contains considerable humus, but much of it is yellow or red, instead of brown or black, from the subordination in quantity of the humus to the ferric hydrate. The greater part of the soil of flood plains is sufficiently dry during a growing season for such crops as corn and cotton. The clays are slightly calcareous and occasionally sufficiently so to give rise to the so-called "buckshot" soils such as are found over portions of the Mississippi flood plain.[1] The subsoils of such plains are observed to carry more compact clay and less humus than the soil, the carbon thus gradually disappearing with depth in aerated soils.

Only in the lower bottoms or abandoned ox bows is the land so saturated with moisture that swamp vegetation dominates, organic

[1] E. W. Hilgard, *Soils in the Humid and Arid Regions*, 1906, p. 116.

matter indefinitely accumulates, and the iron is eliminated or at least reduced partly to the ferrous conditions, giving rise to the blue and green clays found in the subsoils of certain undrained lands. From the discussion on the climatic significance of color, as given in a later portion, it is believed that the usual yellow or brown of such flood-plain deposits frequently deepens upon the consolidation into shades of red or deeper brown. When such flood-plain deposits are buried and lithified the upstream portions will consequently be found somewhat more arenaceous, varying from red to brown sandstones and usually inclosing red, green, and some black shales; the last in very subordinate quantity. Over the terminal land portions of the deposit on the contrary the sandstones should be finer grained and the quantity of shales should increase. With this increase in shales, grey, green, and black varieties should be relatively more abundant and thin lenticular discontinuous coal beds may be expected to occur. Thick, uniform, and widespreading coal deposits are, however, theoretically impossible, since the swamp areas are restricted to the lowest-lying portions of the plain.

Organic characteristics.—A forest growth normally covers the entire surface of such flood plains, varying from mesophytic to hydrophytic types, salt marshes marginal to the sea and internal shallow lakes alone being occupied by reedy growths. The alternate wetting and drying occurring in such soils leads to the rapid humification of animal and vegetable substances, and ultimately to their complete destroyal. Consequently, but few fossil evidences will remain beyond the casts of leaves and trunks occurring in the lighter-colored shales and sandstones, and the preservation of some carbonized tissues in the occasional black and coaly shales.

Conclusion on unappreciated extent of such deposits.—In conclusion it may be said that the deposits of intermittently rainy climates are of a chemical and organic character intermediate between those of continually rainy climates on the one hand and those of a subarid or arid character on the other, lacking the sharply distinguishing characteristics of each. In consequence of the absence of such distinctive marks such deposits, while abundant, may be the most difficult of continental formations to distinguish and convincingly separate from those of shallow-water, off-shore marine origin.

The section of the Ganges delta given by the Calcutta borehole shows no trace of marine deposits, but on the other hand the proofs of land surfaces in the form of ancient swamp deposits, even in this marginal portion of the delta, were encountered only at two levels in the 481 feet of the boring.[1] Scattered vegetable matter and the bones of terrestrial mammals and fluviatile reptiles which were found, while suggestive of continental deposition, may possibly occur in off-shore marine deposits and alone do not conclusively demonstrate the continental origin. Farther inland, at Umballa, on the watershed of the Indo-Gangetic plain, a bore-hole 701 feet deep passed through alternations of sand and clay, the colors usually red or brown but with some clays blue and black. In places the bore-hole encountered a few pebbles and bowlders, but no mention is made of organic remains, which according to Medlicott and Blanford occur but rarely in the alluvial formations of the Gangetic plain.[2] Numerous layers of Kankar (concretionary strata of calcium carbonate) suggest the previous existence at this place of the semiaridity which now prevails in that region. The Mississippi delta shows much of the same characteristics as that of the Ganges at Calcutta. Consequently, where sands and clays or their consolidated representatives constitute a formation with no trace of marine fossils but possessing even fragmentary remains of land life, it is to be concluded with high probability, if no other evidence overweighs the decision, that the entire formation is continental and, further, if no positive marks of other climatic conditions are evident, that it was probably formed on a river flood plain under the intermittently rainy climates, which, though at times diminished and again magnified in importance, have yet existed uninterruptedly through all geologic time and formed those shifting zones within which the chemical activities of the atmosphere and the biologic forces of terrestrial evolution have found their fields for fullest action.

EFFECTS OF SEMIARID CLIMATES

Chemical and structural characteristics.—Semiarid climates are those where irrigation is usually necessary for the maturing of crops

[1] Medlicott and Blanford, *A Manual of the Geology of India*, Part I, 1879, pp. 397–400.

[2] *Op. cit.*, pp. 401, 402.

or where protracted periods of drought are to be expected during certain seasons of the year. In temperate latitudes this corresponds roughly to between ten and twenty inches of annual rainfall. Under such conditions, as illustrated over the High Plains of the United States and much of the Cordilleran province, the humus is oxidized out of the soil more rapidly than in more rainy climates, being deficient in amount but rich in nitrogen; the iron is not leached or concentrated, except in the presence of occasional shallow lakes or swamps; the soil is uniformly high in potash, lime, and magnesia. The potash is, moreover, largely in the form of comminuted orthoclase, giving less plasticity to the finer elements of the soil.[1] Very little distinction is to be noted between the soil and subsoil of alluvial plains.

The swampy portions of the flood plain largely become dry during the long dry season, excluding fishes and offering favorable breeding-places for mosquitoes during the times that the swamps exist. The delta regions of subarid climates are consequently particularly malarious. As examples of such deltas may be cited those along the north shores of the Mediterranean. The Gedis, flowing into the Gulf of Smyrna, possesses extensive delta swamps dry during the summer,[2] while the small proportion of swamp in the case of the Nile delta in a truly arid climate is to be compared with the extensive swamps of the Mississippi. Other factors besides climate, however, may assist in governing the ratio of swamps in the latter cases. The thorough seasonal oxidation which is thus allowed of nearly all deposits except those made in permanent water bodies should result, upon their incorporation into the geological record, in a marked dominance of deep-red and brown shales and sandstones, a moderate amount of variegated shales, confined almost entirely to the marginal portion of the deposit, and few or none holding carbon. Lime will exist disseminated in noticeable amount through both shales and sandstones and may occasionally give rise to markedly nodular or solid calcareous strata.[3] The microscope should show some muscovite and in addition a noticeable amount of feldspar in the finer portions

[1] E. W. Hilgard, *Soils*, 1906, chaps. xx, xxi.

[2] G. R. Credner, "Die Deltas, ihre Morphologie, geographische Verbreitung und Entstehungsbedingungen, *Petermann's Mitth. Ergänzungsheft*, No. 56, Vol. XII, 1878, Plate I.

[3] Medlicott and Blanford, *Geology of India*, 1879, Part I, chaps. xvi, xvii.

of the rock. The contrast between the river deposits of humid and subarid regions is well brought out by the comparison of the alluvium of the Indo-Gangetic plain with that of the Brahmapootra in Assam, the material in both cases coming from the same mountain system.[1]

The most marked chemical distinction of subarid flood-plain deposits from those of truly arid regions is found in the small quantity of evaporation deposits of calcium carbonate, gypsum, and salt, but especially of the two latter. Lime may be quite abundant, as shown by the Kankar of the Indo-Gangetic plain, its importance depending largely upon the quantity in solution in the river water. Gypsum and salt, however, formed by the evaporation of salt lagoons bordering the sea, are largely washed out by the rains and floods of the rainy season. As gypsum and salt impregnations of clay strata they may be preserved and sometimes as purer deposits of salt, as illustrated by the deposits now occasionally formed on the Rhone delta, as noted long since by Lyell,[2] in a climate which approaches subaridity. Such deposits cannot be formed, however, in anything like the areal extent or thickness with which they may occur in truly arid regions. Gypsum in delta deposits is less an indication of aridity than salt, since the former is precipitated upon the evaporation of 37 per cent. of normal sea water while the precipitation of salt only begins when 93 per cent. has been evaporated. It is to be noted, however, that the majority of recent sediments containing gypsum are found in arid climates, and where occurring as impregnations in ancient deposits which were not laid down in contact with sea water would seem surely to indicate a high degree of subaridity bordering upon truly arid conditions.

The alluvial soils of semiarid flood plains are particularly liable to become deeply mud-cracked during the seasons of drought, but this cracking may or may not be preserved in the sedimentary record.[3] Over the regions of alternating sands and clays where the clay is not calcareous the conditions are most favorable for the formation and preserval of mud cracks. The importance of mud-cracking in further drying out the soil and tearing the roots of plants has recently been

[1] E. W. Hilgard, *Soils*, 1906, pp. 410–14.

[2] Charles Lyell, *Principles of Geology*, 9th ed., 1853, p. 259.

[3] J. Barrell, *Journal of Geology*, Vol. XIV, pp. 528–33.

pointed out by Hilgard.[1] The climatic point where mud-cracking becomes broadly effective upon the clays of a flood plain is therefore rather a critical one tending to separate the floral characteristics of well-watered from subarid climates.

Floral characteristics of semiarid flood plains.—One of the most secure means at present commonly used to determine the climate of a past age consists in the study of a fossil fauna and flora, the identification of genera and species, and the inference that the optimum climatic environment for such organisms has remained the same from the past to the present time. As examples may be cited the conclusions in regard to the warm polar climate of the Miocene based on the presence of magnolias in Greenland and the same in Mississippian times as determined by fossil corals in the rocks of Spitzbergen. Such strictly paleontological sides of the problem are beyond the province of the present article, but there may be profitably considered the relations between climate and the kind of fossils to be expected and certain general adaptive characteristics of plants or animals to arid or moist, cold or warm conditions, especially when these are of a nature which may be preserved. The present statements will be chiefly confined, however, to the effects of semiarid climates upon vegetation.

The vegetation of the flood plains of semiarid climates is more largely arboreal than that of the inter-stream slopes.[2] Many large tracts of the flood plain away from the river banks are, however, either sparsely covered with trees or given over to grass land. Even the latter may find difficulty in existing where an unfavorable nature of alluvial deposit is added to the unfavorable conditions of a hot or dry growing season.[3] The occupancy of the soil by grass or forest depends upon the underground water. For forests there must be an adequate amount of moisture in the subsoil during the growing season, though this water may have come from winter floods or rains. For grassy plains the water in the subsoil is immaterial, the essential con-

[1] *Soils*, 1906, p. 112.

[2] A. F. W. Schimper, *Plant Geography* (Eng. trans.), 1898, Map 3.

[3] Views of piedmont and terminal flood plains of the semiarid belts of the United States may be found in various reports. For a study, with photographs, of the vegetation of the Rhone delta of the Mediterranean in a climate which approaches semiaridity see *Flahault et Combres*, Sur la flore de la Camargue et des alluvions du Rhone, *Bulletin de la société botanique de France*, T. 41, 1894, pp. 37–58.

dition being a moist soil during the season of growth.[1] Although the level of the ground water in flood plains of even subarid climates may lie not many feet below the surface, the alternate stratification of fine sand and clay which is frequently present is very unfavorable for a forest vegetation. The clay is capable of carrying the water upward to a greater height, even as high as ten feet, but transmits it very slowly. The sand, on the other hand, cannot lift the capillary water more than one or two feet, but does this very quickly.[2] If the upper portion of a sand stratum is dry, the plants cannot feel the moisture below and will fail to send roots after it. In the presence of such strata a vegetative covering of bunch grass is to be expected, leaving no appreciable organic record. A deep loamy soil favorable for storing water and for its capillary rise is the most favorable condition for the growth of trees and shrubs over semiarid flood plains. The roots in such cases strike downward rather than horizontally and may penetrate to great depths, twenty feet being not uncommon.[3] The angle of penetration of fossil roots is therefore a matter of importance from a climatic point of view. The strong oxidation acting at the surface normally destroys all vegetable tissues before they become buried in the course of time below the deep zone of oxidation, but there is a chance of finding casts of downward-branching rootlets in massive arenaceous shales and more rarely of vegetable remains buried by superficial accumulations. It is seen, therefore, that in the river deposits of semiarid climates casts of logs are most likely to be preserved in the sands deposited in the neighborhood of stream channels. At a distance from the channels, wetting and oxidation would tend to destroy the logs and larger fragments if such existed, before sufficient time had elapsed for burial. Root impressions of trees in such regions would be of more common occurrence than trunks and confined possibly to what were originally deep loamy sands. The herbaceous types of vegetation, however, are the more common over the well-drained portions of truly semiarid flood plains, and the plant impressions recorded in the strata would consequently be of small size compared to those of the large and luxuriant vegetable forms of more rainy climates.

[1] *Op. cit.*, pp. 164–75.

[2] E. W. Hilgard, *Soils*, 1906, pp. 202–13.

[3] *Loc. cit.*, pp. 167–83.

The above discussion is based on the present floral societies, composed almost wholly of flowering plants. The conclusions, however, in regard to the climatic relations of herbaceous and arboreal vegetation may with probability be extended backward in time to ages as early as the Devonian, when all plants were either cryptogamic or gymnospermous, since in the later Paleozoic, long before the advent of the Mesozoic phanerogams, plant societies existed then as now which included forms from arboreal to herbaceous and ranged in adaptation from hygrophilous to xerophylous. The present usual restriction of cryptogamic vegetation to small forms occupying habitats moist, shady, or cold, habitats not strongly sought by the higher vegetation, did not then necessarily hold; conditions to some extent perpetuated in Australia, where tree ferns still abound in the coastal districts of New South Wales and Victoria, and vascular cryptogams with xerophytic adaptations are known to occur in other portions of the island continent.

In illustration of these conclusions a comparison may be made of the fossil vegetation of the Mauch Chunk (Mississippian) shale of eastern Pennsylvania, believed by the writer from other considerations to be a continental deposit of a semiarid climate,[1] with the flora of the overlying coal-measures, believed to be continental deposits of a climate cool and rainy. In the Mauch Chunk strata, as observed by the writer, impressions of small plant fragments are not uncommon, consisting of first, the fragments of slender grasslike reeds probably belonging to the equisetae; second, impressions of flattened, straplike coarser stems and leaves up to an inch in width and exhibiting suggestions of paralled venation; third, impressions of stems with close-set spiny leafage, the spines not being over half an inch in length; fourth, casts of roots showing branching rootlets, the latter clothed with fine tendrils. The roots occur in massive argillaceous sandstones and in favorable cases are exposed by the rock fractures for depths of a foot with indications of being considerably more extensive. A striking feature of those root casts found in place is that they branch downward and not horizontally. Other observers have detected a leathery character in certain of these plant impressions. No casts of logs have

[1] J. Barrell, "Origin and Significance of the Mauch Chunk Shale," *Bulletin of the Geological Society of America*, Vol. XVIII (1907), pp. 449–76.

been seen by the writer or described by others and no carbon from the plant tissues is ever preserved. These characteristics are opposed throughout to those of the overlying carbonaceous beds of the true Carboniferous. In these the carbon is preserved, impressions of logs are abundant, the vegetation is coarse and luxuriant, and grasslike forms give place to a water-loving forest growth. The roots preserved in the underclay show no such tendency to penetrate constantly downward and in the case of the stigmaria are developed into stolen-like forms such as are possessed by many existing marsh plants.

The conclusions as to climate, based on the character of the vegetation in the case of these late Paleozoic formations and determined from adaptive relations observed to exist at present in quite different divisions of the vegetable kingdom, are thus seen to be in harmony with conclusions based on a number of other and independent lines of evidence. The latter, however, cannot be given at this place.

The animal life also shows adaptations to the climate, but these are far from being as strongly marked or so dominated by climate as in the case of plants, so that neither can a discussion of such general characteristics be considered under the present subject.

EFFECTS OF ARID CLIMATES UPON FLUVIAL AND PLUVIAL DEPOSITS

Chemical characteristics, evaporation deposits.—Arid climates, those of true deserts, typically possess no drainage to the sea and no agriculture is possible without either natural or artificial irrigation. Fluvial and pluvial deposits may, however, be abundantly developed, owing to the torrential nature of the occasional rains acting upon a loose and unprotected mantle rock. In this hasty transfer of disintegrated rather than decayed rock débris but little leaching is likely to occur, soluble and insoluble materials remaining together, the two tending to become somewhat separated by later and local action. The rainfall of such regions is, in the temperate zone, less than ten inches per year.

As noteworthy examples of deltas in arid climates may be cited those of the Volga, the Indus, the Nile, and the Colorado. The lime in such may form still more striking inorganic deposits than the "Kankar" of the subarid flood plains of India, forming such incrustations

as the massive travertine and caliche deposits of Arizona and Mexico.[1] In other cases, however, the content of lime may be no higher than in the deposits of subarid flood plains, the percentage of dissolved lime in the river water to undissolved detritus apparently having a strong influence in this respect. For example, the deltas of both the Rhine and the Rhone, especially the latter, show a considerable proportion of calcium carbonate due to the highly calcareous nature of the formations subjected to erosion, supplemented in the case of the Rhone by the approach toward a semiarid climate over its delta in the Mediterranean Sea. This delta consists in large part of sand cemented by lime.[2] In the deposits of the Nile delta, on the other hand, calcium carbonate is probably no more or possibly even less abundant than in the case of the Rhone. Analyses by Regnault of fresh Nile mud gave 22 per cent. of carbonates, of old Nile mud gave 11 per cent. Other analyses by Knop from other localities gave, however, only 4.1 to 4.7 per cent. of carbonates in the dried inorganic residues of Nile mud.[3] These may be compared with 0.1 per cent. of $CaCO_3$ as the average content in three alluvial soils of the Ohio Valley and 1.38 per cent. of $CaCO_3$ in two alluvial soils of the Mississippi Valley.[4] In the delta muds of arid climates the proportion of true clay may be low, and alkalis exist, largely either in the form of comminuted feldspar or as soluble alkaline salts in the surface soil. Brine pools and gypsum deposits will be not uncommon in the lower areas, especially near the margins of the deltas. Dense reedy jungles and fever-breeding salt swamps frequently dry at some season of the year may be common, but the presence of evaporation deposits with the decolorized shales is a characteristic which separates them from those of semiarid climates.

Those parts of the potash and soda which are dissolved from the silicate minerals and form alkali crusts or flat lands in arid regions are kept near the surface, being carried upward by capillary action in the dry season and washed downward a short distance by the occa-

[1] W. P. Blake, "The Caliche of Southern Arizona," Abstract, *Engineering and Mining Journal*, Vol. LXXII, 1901, pp. 601, 602.

[2] G. R. Credner, "Die Deltas, ihre Morphologie, geographische Verbreitung und Entstehungsbedingungen," *Petermann's Mitth. Ergänzungsheft*, No. 56, Vol. XII, 1878, p. 16.

[3] G. R. Credner, *op. cit.*, p. 15.

[4] G. P. Merrill, *Rocks, Rock-Weathering, and Soils*, 1906, p. 351.

sional rains or floods. The diagrams given by Hilgard show that in clay lands the bulk of the alkali is within two feet of the surface and in sandy lands within seven feet.[1] Medlicott and Blanford state that in the worst alkali tracts of India sweet water is obtainable at depths below sixty to eighty feet.[2] Except in the most arid regions the soluble alkali salts are thus seen to be prevented from accumulating through the strata.

Combinations of Fluvial and Aeolian Structures.—The surfaces of arid flood-plains and to a lesser extent those of semiarid climates are dry and barren for a considerable portion of each year, and the detritus becomes reworked by wind action, with the result that in flood plain deposits of desert climates fluvial, pluvial, and aeolian formations are all of wide occurrence and brought into immediate juxtaposition, producing combinations of structures which may be more or less readily recognized in the buried strata. The clayey layers deposited by flood waters crack upon drying into polygonal discs which curl upward on their edges, giving concave mud-cracked surfaces. The fine silt and sand, not possessing coherency when dry, and not being held by vegetation, give rise to intolerable dust storms. The finer silt may cover the adjacent regions with loess and the coarser portions, derived from the stream channels, may be the source of widespread dune sands, such as mantle the deltas of the Indus and the Helmund, burying many ancient cities and subjecting the still exposed ruins to aeolian scour.

The more distinctive structures resulting from the combinations of water and wind action may be classified and described as follows:

First, *mud-cracks filled with aeolian sands.*—Silt and sand will be blown over and fill up the cracks developed by the drying of argillaceous water-laid deposits. Consequently, the sand is filled in under the raised rims of the polygonal discs and becomes continuous with the mantle of sand above. In this way, the concavity upward of the individual plates is preserved and the mud-cracks are not obliterated, even in a silty clay which would slack and crumble immediately upon being rewet by the advancing waters of the following inundation. Experiments by the writer go to show that the upturned edges of the

[1] *Soils*, 1906, chap. xxii.

[2] *Geology of India*, Part I, 1879, p. 413.

clay plates would not usually hold their form while the broad sweep of sand-laden waters should deposit clean sand both under the edges and over the plates. The concavity of the plates thus testifies to aeolian burial and such may be distinguished from mud-cracked flats buried by fluvial action. Since writing a previous article on "Mud Cracks as a Criterion of Continental Sedimentation,"[1] evidence has come to hand from widely separated regions indicating the great geological significance of aeolian-filled mud-cracks in the flood plain deposits of arid climates. A. W. Rogers writing from South Africa makes the following statement:

KHEIS, GRIQUALAND WEST, May 19, 1907.

Today . . . I happen to be camped on the narrow flood plain of the Orange River which is a fine place for the observation of mud-cracks. The mud flats are exposed for months and even years before being covered again by water. The mud is a gray-brown silt and the cracks become filled with the deep red Kalahari sand from the north. In places the sand advances as fairly high dunes and buries the mud deeply. Generally, however, small thicknesses of the sand are laid down on the mud.[2]

Isaiah Bowman, writing from South America, makes the following statement:

IQUIQUE, CHILI, May 4, 1907.

Along the inner edge of the Desert of Tarapacá, roughly between the towns of Tarapacá and Quillagua, Chili, the piedmont gravels, sands, silts, and muds extend for over a hundred miles, flanking the western Andes and forming a transition belt between these mountains and the interior basins of the coast desert. The silts and muds constitute the outer fringe of the piedmont and are interrupted here and there where sands are blown upon them from the higher portions of the piedmont or from the desert mountains and plains on the seaward side. Practically no rain falls upon the greater part of the desert and the only water it receives is that borne to it by the piedmont streams in the early summer from the rains and melted snows of the high plateau and mountains to the eastward. These temporary streams spread upon the outer edge of the piedmont a wide sheet of mud and silt which then dries and becomes cracked, the curled and warped plates retaining their character until the next wet season, or until covered with wind-blown sand. The wind-driven sand fills the cracks in the muds and is even drifted under the edges of the up-curled plates, filling the spaces completely. Over this combined fluvial and aeolian deposit is spread the next layer

[1] Joseph Barrell, *Journal of Geology*, Vol. XIV (1906), pp. 524–68.

[2] Personal communication to the author.

of mud, which frequently is less extensive than the earlier deposits, thus giving abundant opportunity for the observation of the exact manner of burial of the older sand-covered stratum. The process described above is thought to be of particular interest on account of the generality of its occurrence in this desert.[1]

Ellsworth Huntington contributes the following statement concerning relations observed by him in central Asia:

The floor of the great desert basin of Lop in western China furnishes examples of various associations of mud-cracks with aeolian deposits.

At Yartungaz, 450 miles southwest of Lop-Nor, the floor of the basin consists of a fine-grained saline silt which appears to have been deposited in broad, shallow playas. The surface of the ground is smooth, and there is no sign of buckling, but polygons from three to twelve feet in diameter are plainly visible. The division lines stand out as dark markings dividing the light gray plain into innumerable fairly symmetrical polygons. The prominence of the markings is due to the fact that they are composed of sand which seems to have been blown by the wind into the original cracks in the plain.

A hundred miles farther to the southeast, near Chira, the barrenness of the wind-swept plain of piedmont gravel at the base of the Kwen Lun mountains is slightly relieved by lines of grassy weeds arranged in polygonal patterns like those of Yartungaz. Digging among them, one finds that the plants grow in fine brown sand which fills old cracks in a hard deposit of fine and very saline gravel. The sand is of the same texture as that of the small dunes of the neighborhood.

The most striking case, however, is that of the old bed of the expanded glacial lake of Lop-Nor. For scores of miles a layer of impure rock salt, from one to three inches thick, has split into polygons ranging from five to twelve feet in diameter. The edges have buckled up in exactly the same manner as the edges of ordinary mud-cracks, and frequently stick up two or three feet. The underlying hollows are often partially filled with sand which has been blown in from the distant shores of the lake-bed.[1]

Thus it is seen that this peculiar method of preserval of mud-cracks is widely prevalent at the present time upon the flood-plains of arid regions in various parts of the world. The writer has observed that the same structure has been also widely developed in certain ancient formations.

In the Mauch Chunk shale of Pennsylvania the mud-cracked shale partings between sandstone strata are frequently in the form of tesselated polygonal plates concave upward, the covering layer of

[1] Personal communication to the author.

sand filling the cracks and passing beneath the upraised rims of the plates.[1]

In the Triassic of the Connecticut valley the same structure may be frequently observed, the concave shale plates being in this formation frequently buried in undecomposed feldspathic sand.

Second, *interbedding of fluvial and acolian sands.*—Gravel and sands which are originally transported by fluvial or pluvial actions upon flood plains in arid climates are later subjected to the action of the wind. Truly fluvial sands and gravels consequently become repeatedly interbedded with acolian sands, and Huntington states that this is a striking and frequent relation, as seen in the freshly exposed terrace faces on the margins of the desert basins of Asia.

The fluvial and pluvial deposits are characterized by a more heterogeneous and coarser nature and by the absence of the characteristics which mark acolian sands. It is necessary therefore to summarize some of the distinguishing features of the latter deposits. Dune sands are deposited on the sloping surfaces of the leeward faces of dunes and may reach heights of several hundred feet. At the bottom the inclined layers decrease in dip and pass horizontally to the intervening desert surface. In a region of accumulating sands each passing dune leaves its basal portions to be covered by the march of the following succession of dunes, so that the lower portion of this cross-bedded structure becomes deeply buried and permanently preserved.

As has been recently pointed out by a number of geologists, the characteristic features of such dune sands, separating them from fluvial or littoral deposits, consist consequently in the homogeneous nature, the development of "millet seed" texture, and the presence in striking degree of cross-bedding which may reach great thicknesses. The cross-bedded strata are abruptly truncated above but flatten out and become tangent to the general stratification at the bottom. It is probable that a number of arenaceous formations which have been customarily considered marine are, on the contrary, of such mixed fluvial and acolian origin. For example, Davis, Huntington, and

[1] For illustrations see Joseph Barrell, "Origin and Significance of the Mauch Chunk Shale," *Bulletin of the Geological Society of America*, Vol. XVIII (1907), Pls. XLIX, L, and Fig. 1, p. 457.

Goldthwait have raised the question if such has not been the mode of origin of the Triassic and Jurassic sedimentary formations of the Colorado plateaus.[1]

Third, *scattered and facetted pebbles.*—In truly aeolian sands the size of the material is rather sharply limited, but in stream channels pebbles or larger fragments may be carried indefinite distances from the fields of erosion. Cloud-bursts and sheet-flood deposition may also sweep large fragments along with the fine, but such action is necessarily more closely limited to the vicinity of the sources of sedimentary supply. In such ways pebbles of various sizes may be clustered or scattered through a finer textured deposit without necessarily implying transportation by either the roots of floating trees, or floating, or glacial ice. Pebbles carried by each of these agencies will be apt to exhibit distinctive characteristics and associations. Those carried by fluvial or pluvial action upon arid flood-plains are the ones to be here considered. The association with various indications of climatic conditions such as those already considered may often suggest the mode of origin. It seems probable, however, that in many instances such pebbles should carry their own evidence through being subjected to wind scour upon the drifting away of the enveloping sand. They would become facetted in consequence, giving rise in the consolidated conglomeratic sandstone to the occasional presence of "dreikanter." Such peculiarly facetted but unstriated pebbles have been collected from a number of formations, dating back even to the pre-Cambrian, but have sometimes been claimed to be of glacial origin. An instance where the hypothesis of aeolian origin appears to offer by far the best explanations has recently been described with illustrations by Lisboa in the case of pebbles which are probably of upper Mesozoic age from the central plateau of Brazil.[2]

Organic characteristics.—Over the more truly desert portions of arid flood plains the life is unimportant at the present time, and in past times has been equally unimportant, if not more so, since the

[1] E. Huntington and J. W. Goldthwait, "The Hurricane Fault in the Toqueville District, Utah," *Bulletin of the Museum of Comparative Zoölogy at Harvard College*, Geological Series, Vol. VI, No. 5, 1904, pp. 210–17.

[2] "The Occurrence of Facetted Pebbles on the Central Plateau of Brazil," *American Journal of Science*, Vol. XXIII, 1907. pp. 9–19.

progress of evolution has been to progressively specialize life forms for such extremely unfavorable habitats. The present relations are briefly as follows:

A sparse vegetation occurs over the drier or more alkaline portions of the plains. Other portions may be covered with dense scrub as seen in the Australian bush. Along the streams tree growth commonly occurs, and hence casts of roots and leaves might be left. In the swamps reed growths are abundant and may become fossilized and associated with white or greenish clay strata.[1] Animal bones embedded in the desert plains stand excellent chances of preserval and observation of the accumulating prairie loess has led Matthew to believe in an aeolian origin for the fine-grained calcareous clays of the White River Tertiary formation covering a considerable area of the Great Plains of the United States,[2] though these tracts are presumed not to have been really arid but rather subarid in climate. The fossil fauna of this deposit as Matthew has shown is such as can be explained by the aeolian hypothesis, but not by one of lacustrine origin.

Ease of recognition in the geological column.—From these characteristic features of the river plains of arid regions it is to be concluded that their fossil representatives should be rather readily recognized. In the marginal region of the delta and for some distance inland beds of salt, gypsum, and marl are interstratified with red shales, in which, however, occasional decolorization may occur. Farther inland the strata will show fewer pure evaporation deposits, but these minerals will still be diffused through the strata. Carbonaceous matter will be practically absent, but well-preserved animal remains may be abundant. Dune sands, characterized by cross-bedding and a high degree of rounding, giving "millet seed" sand beds such as those which Phillips has described from the English Triassic,[3] will be associated with true river deposits, sometimes mud-cracked, and the whole will be characterized by a relative absence of rock decay in the process of sedimentation.

[1] Huntington, "The Basin of Eastern Persia and Sistan," *Carnegie Institution*, 1905, pp. 279–87.

[2] W. D. Matthew, "Is the White River Tertiary an Aeolian Formation?" *The American Naturalist*, Vol. XXXIII, 1899, pp. 403–8.

[3] J. A. Phillips, "On the Constitution and History of Grits and Sandstones," *Quarterly Journal of the Geological Society*, Vol. XXXVII, 1881, p. 26.

THE CLIMATIC SIGNIFICANCE OF COLOR

One of the most obvious features of the sedimentary rocks is their color, due partly to climatic, partly to various other, conditions of origin. Among the latter Walther calls attention to the fact that—

> The colors of continental deposits are different according as they are formed above or below a water surface. The deposits in the courses of streams or in interior seas have usually either greenish or bluish colors which also characterize the marine deposits of the continental shelves. The typical continental deposits, formed upon the dry land, are characterized by bright clean colors. The carmine or vermilion tropical laterite, the red-colored sand dunes of the Coromandel lowland and the inner Arabian desert, the yellow or brown loam and loess deposits of the steppes, the white or yellow dunes of the coast lands or the Sahara are convincing examples.[1]

The influence of climate as distinct from other conditions of origin is rendered evident on contrasting the brilliant reds of the moist tropical or subtropical regions with the yellow or dark soils of colder temperate climates or the prevailing ashen gray of deserts. The significance of color in the older rocks cannot, however, be directly inferred from the study of modern deposits since the changes which transform a soft sediment into a solid rock may also conceivably alter the color.

For the purposes of the present discussion, the colors of shales and sandstones may be grouped under three heads: first, red; second, light and variegated; third, gray to black. Each of these color groups is of importance and includes appreciable portions of the sedimentary rocks. On account of the diversity of views, however, respecting the significance of red and its climatic bearings, it will be necessary greatly to enlarge the discussion upon that topic.

The origin of red formations.—Red shading into brown is one of the most frequent colors of ancient continental shales and sandstones and may also occur among those of marine origin. That there is no unanimity in regard to its significance among geologists may, however, be gathered from an examination of the literature. Russell has given a full review of these views.[2] Certain authors have supposed

[1] *Einleitung in die Geologie*, translated from *Lithogenesis der Gegenwart*, 1893–94, p. 725.

[2] "Subaerial Decay of Rocks and Origin of the Red Color of Certain Formations," *Bulletin 52*, U. S. Geological Survey, 1899, pp. 47–56.

that the red is due to igneous agencies, oxidizing iron pyrites, or to volcanic dust or the heat of igneous intrusions. All such hypotheses fail, owing to the widespread occurrence of red rocks, their uniform color, and the absence of metamorphism. Another group of hypotheses ascribes the oxidation to weathering at the time of origin of the sediments and this is undoubtedly correct, the iron peroxide being a component part of the accumulating sediments. Nearly all writers, however, assume that the oxide which is now more or less completely dehydrated and consequently red was in this dehydrated state at the time the sediments were deposited. This assumption runs through the work of Russell and is the basis of many such statements as that of Darton that "red shales and sandstones, such as make up the red-beds, usually result directly from the revival of erosion on a land surface long exposed to rock decay and oxidation and hence covered by a deep residual soil. . . . . There is such uniformity of the deep-red tint that this is undoubtedly the original color."[1] Russell considers that the incrustation of the sandstone grains of the Newark formation by ferric oxide, resembling that surrounding the grains of quartz in the residual soil of the southern states, indicates that the grains were transported without sufficient wear to remove the original incrustation. From the distribution of present red earths, he further concludes that their formation requires the presence of heat and moisture. All such special modes of origin, however, are difficult of acceptance in view of the great predominance of red, or red-brown in ancient ferruginous formations and the comparative absence of yellow tones such as dominate modern alluvium.

In view of such a conflict of opinions and the special nature of the hypotheses used to explain the general nature of the phenomenon, the need of discussion is seen. Certain essential facts which have bearings on the conclusions may be stated as follows: As indicating the influence of a moist climate, Russell notes the brilliant reds and yellows of the soils of the South Atlantic states as compared with the ashen tints of the Mojave desert,[2] and he elsewhere speaks of the creamy-white color of the playa-lake deposits of Nevada and Arizona,

[1] "Geology of the Bighorn Mountains," *Professional Paper No. 51*, U. S. Geological Survey, 1906, pp. 105–7.

[2] I. C. Russell, *op. cit.*, p. 27.

beds exposed during the summer months to temperatures of from 110° to 120° Fahr. in the shade.[1] As indicating the influence of heat may be mentioned the uniform restriction of red soils, neglecting those derived directly from red formations, to the warm temperate and especially the torrid zone. That the contrast is not due to the younger age or glacial origin of the soils of the cold temperate zones is found upon examination of driftless areas in such regions. As indicating the influence of prolonged exposure to the air, Crosby notes that it is the older soils and especially the surface portions in the warm regions which show red to a striking degree.[2]

Where reds in surficial formations are noted in arid regions they are frequently the accompaniments of aeolian action. Dune sands may be white, yellow, or red. Red deserts have been noted in both Africa and Asia and Phillips has shown that the red sands of the Arabian desert owe their color to a coating of ferric oxide deposited after the grains of sand had become round. The source of the iron oxide, which comprised about 1–500 of the total weight, he was unable to determine.[3] All these facts emphasize the influence of lapse of time and the presence of moderate heat, such as that of the torrid regions, as causes sufficient partially to effect the dehydration of ferric oxide, even without the agency of pressure; thereby transforming the yellow and light-brown colors into the brilliant reds which characterize the tropical regions of rainy climate.

In view of these facts, one of the chief true causes of the red color of the older ferruginous formations seems to have been reached by Crosby, whose statements are as follows:

> The dehydration of the ferric oxide is not wholly dependent upon heat or pressure or any obvious extraneous agency, but it is in a large degree, apparently, a spontaneous process. Of this we have abundant evidence in nature and in the laboratory. When the iron, which exists in the various silicate minerals chiefly in the ferrous state, is liberated and peroxidized during the decay of these species, it combines naturally with a very large and indefinite proportion of water, forming the yellow hydrate, which is seen as a flocculent or a gelatinous colloid in the waters of springs, bogs, and marshes, and when the hydrate is obtained as

[1] *Op. cit.*, p. 42.

[2] On the contrast in color of the soils of high and low latitudes, *American Geologist*, Vol. VIII, 1891, p. 77.

[3] "The Red Sands of the Arabian Desert," *Quarterly Journal of the Geological Society*, Vol. XXXVIII, 1882, pp. 110–13.

a precipitate in the laboratory. But this colloid mass, even if immersed in water and entirely undisturbed, gradually and spontaneously gives off a large part of the water which the ferric oxide has so greedily absorbed when in the nascent state; and it appears thus, as it slowly solidifies and hardens, to pass in succession through the forms of the various native yellow hydrates—limnite, *xanthosiderite*, and limonite, to göthite. That this progressive change continues is evident from the fact that these yellow hydrates are gradually replaced in the older formations by the red hydrate (turgite) and by ferric anhydride (hematite). When occurring as original or contemporaneous, and not as secondary, deposits, the yellow ores of iron are found, as a rule, only in the later rocks; while the red ores are generally restricted to the earlier rocks. This genetic relation of the yellow and red ores is one of the most familiar and generally accepted facts in geology. However recent the origin of the red ore (turgite or hematite) may appear to be in any case, we naturally infer that it was first yellow, and that it has passed slowly or rapidly, as the case may be, but gradually, through the series of yellow hydrates. . . . .

If it be conceded that the dehydration is virtually, if not absolutely, spontaneous, and there is no apparent alternative, it follows that the color of a deposit, so far as it is due to ferric oxide, is, other things being equal, a function of its geological age. In other words, the color naturally tends with the lapse of time to change from yellow to red; and, although this tendency exists independently of the temperature, it is undoubtedly greatly favored by a warm climate. Applying this principle to the sedimentary soil of the South, we find that the superficial portion is red, not alone because it is exposed to a higher temperature than the subjacent yellow clay, but also because it is the oldest part. On the other hand, the limited occurrences of post-glacial sedimentary detritus in the North are, in the absence of the favoring climatic influence, still too young to exhibit the change of color even superficially.[1]

Judging from the later expressions of opinion, this article does not seem to have received the attention which it deserves.

Spontaneous dehydration assisted by heat and favored by time does not appear, however, to be the sole cause of the great contrast in color between the consolidated and the surficial ferruginous sediments, a still more potent cause existing in the dehydration effected by the great increase in pressure and moderate rise in temperature which takes place upon the burial of the material to some thousands of feet beneath later accumulations. The efficiency of pressure in this connection is exhibited in the formation of shales, where about one-half of the combined water is eliminated at temperatures which must be frequently far below the boiling-point, since with the normal gradient

[1] *Op. cit.*, pp. 80, 81.

a temperature of 110° C. is attained only at a depth of about 11,000 feet (3,300 meters). The ferric oxide, holding its water with much less tenacity than the silicate of alumina, seems to respond most readily to the influence of pressure, giving rise to minerals of notably less volume and greater density, apart from the water which is eliminated in the process.

Still a third factor in the development of a red color in ferruginous rocks is found in the physical state of the oxide, as may be seen upon contrasting the brilliant color of earthy hematite with the deep colors of the same mineral in its crystalline form. The red color depends therefore not only upon the presence of anhydrous or partially anhydrous ferric oxide, but also upon a fine state of division and diffusion. Dawson speaks of the very fine state of division of the red coloring matter in the lower Carboniferous of Nova Scotia—

> having indeed the aspect of a chemical precipitate rather than of a substance triturated mechanically. In addition to the oxide of iron distributed through the beds, there is, in the fissures traversing them, a considerable quantity of the same substance in the state of brown hematite and red ochre, as if the coloring matter had been superabundant or had been in part removed and accumulated in these veins.[1]

Hilgard states further that the general red aspect of tropical soils is by no means always accompanied by markedly high percentages of ferric oxide, but the latter is very finely diffused so as to be very effective in coloration. The soils of the arid regions on the other hand are not deficient in ferric oxide.[2] The present writer has also noted that pebbles of feldspar showing glistening cleavage embedded in the red Triassic arkoses of the eastern United States are stained red throughout with ferric oxide while those of quartzite are stained to variable depths and those of vein quartz only along the fractures. The completeness of the staining, its development about the stream-worn surfaces of pebbles, and its presence in all materials, depending only upon their porosity, are indications that this was done after incorporation in the sediments and through a considerable period of time. The above facts seem to show that ferric oxide in rocks is rather readily

[1] J. W. Dawson, "On the Coloring Matter of Red Sandstones and of Greyish and White Beds Associated with Them," *Quarterly Journal of the Geological Society*, Vol. V, 1848, pp. 25, 26.

[2] Hilgard, *Soils*, 1906, pp. 392, 400.

diffusable, permeating the entire rock mass and thereby becoming more effective as a coloring substance. In view of this ready diffusability and ease of dehydration, such a special hypothesis as that of Russell—that the crusts of ferric oxide had been retained by sand grains during their transportation from a residual soil—seems unnecessary and as a general explanation does not apply.

To sum up, it is seen that the cause of the red color in ferruginous rocks as contrasted with the predominant yellows of modern alluvium is to be found in three co-operating causes: First, spontaneous dehydration operates to some extent at the surface in the warmer regions. Second, dehydration under great pressure and moderate temperatures is nearly universal in sediments which become buried and consolidated. Third, diffusion operates under conditions of warmth and moisture, whether these be found at the surface, as in warm and humid regions, or beneath the surface, as may occur in any portion of the earth. By these three means light-colored, yellow or brown muds and sands may become red shales and sandstones. Only in the presence of considerable heat, as on the walls of dikes, or in the presence of some highly dissolving fluid does the tendency toward crystallization or new combination reverse the coloring effects of capillary diffusion.

Red in shales or sandstones is therefore normally assumed, like the hardness, upon the consolidation into a shale or sandstone of any sediment possessing an appreciable amount of ferric hydrate and is no more necessarily original than is the red of a burned brick.

The reliability of these conclusions may be tested by observing the stratigraphic relations of ancient deposits. As a typical example may be cited the Permian red-beds developed east of the Rocky Mountains, which contain conspicuous strata of gypsum and are impregnated with salt, giving thus undoubted evidence of deposition under an arid climate. The same association of salt and gypsum with red shales and sandstones might be cited from Nova Scotia and a dozen other localities.

This is in striking contrast to the usual present development of salt and gypsum in association with gray or yellow sediments. For example, the marginal bottom of the Dead Sea when exposed by unusual dessication shows a surface of bluish-gray clay or marl full of crystals of common salt and gypsum, and light-grays are char-

acteristic also of the salty flats in the Great Basin of the United States. Furthermore, the Red Sea, surrounded by intensely arid lands, shows dominant light yellow as the color of the bottom muds, varying in certain soundings to tones of grayish or brownish yellow.[1] Contrary to what might be expected from the name, the Red Sea contains no red sediment and the origin of the name is in doubt.[2]

From these statements it is seen that, while red in present soils is particularly characteristic of the residual soils of warm moist climates, in ancient deposits it is a usual accompaniment of arid conditions.

Furthermore, that hot climates were not necessary for the origin of certain ancient red shales and sandstones is suggested, but far from proved, by the occurrence of such rocks within the Arctic Circle, Nathorst having found the Old Red Sandstone in Spitzbergen, lat. 79–80° N.[3] On Bear Island, also, somewhat farther to the south, in lat. 74° 30′ N., and again in northern Norway, red strata of this age occur.[4] Turning to the antipodes, it is to be noted that Wilkes in 1840 landed on an ice island off the Antarctic continent in lat. 65° 60′, long. 106°19′ E. He found imbedded in it, in places, bowlders, stones, gravel sand, and mud or clay. The larger specimens were of red sandstone and basalt.[5] The "Challenger" expedition in 1874 in the vicinity of the Antarctic ice in lat. 65° 42′, long. 79° 49′ E., dredged up specimens of igneous and metamorphic rocks and red sandstone.[6]

That a special origin, such as by "the revival of erosion on a land surface long exposed to rock decay and oxidation and hence covered by a deep residual soil," is not necessary is indicated by the very great thickness and uniform color of certain red formations; by the

[1] Joseph Luksch, "Vorläufiger Bericht über die physikalisch-oceanographischen Untersuchungen im Rothen Meere," *Wiener Akademie Sitzungsberichte, Mathematisch-Naturwissenschaftlichen Classe*, Abtheilung I, Band CVII (1898), pp. 636, 637.

[2] Major J. S. King, "The Red Sea: Why so Called," *Journal of the Royal Asiatic Society* (1898), pp. 617, 618.

[3] E. Suess, *Das Antlitz der Erde*, Eng. trans., Vol. II, pp. 68, 69.

[4] A. Geikie, *Text Book of Geology*, 4th ed., 1903, pp. 1012.

[5] *Narrative of the United States Exploring Expedition During the Years 1838–1842*, Vol. II, p. 325.

[6] John Murray, "Deep Sea Deposits," "*Challenger*" *Reports* (1891), pp. 80, 81.

inclusion of conglomerates whose component pebbles frequently consist of fresh blocks of granite, pegmatite, and other rocks subject to decay, testifying to a partial dominance of disintegration over decomposition; by such an example as the Mauch Chunk red shales and sandstones, 3,000 feet in maximum thickness, following immediately upon the gray Pocono sandstone and its gradual transition above into Pottsville conglomerate, red shales alternating with conglomerate horizons.

That conditions of deposition permitting oxidation had much to do with the development of red in the consolidated sediment is indicated by the usual poverty in fossils, especially in those of marine origin; by the repeated intercalation in the Basin of Sistan of pink to brown silts, regarded by Huntington as having been deposited subaerially, with green clays, considered with good evidence as typically lacustrine.[1] As a further illustration, the Wamsutta red-beds of the Carboniferous of the Narragansett basin are regarded by Woodworth as represented south of Providence by the lower strata of the Kingstown coal-bearing series. In the vicinity of Pawtucket the coal-measures underlie the Wamsutta, though somewhat farther north the latter are only separated from the granite by the basal arkose beds of the Pondville group.[2] Woodworth states that the coloring of the Wamsutta red-beds appears to have taken place before transportation. This view, however, leads to difficulties which he states on the same page. All difficulties, seem, however, to be avoided if it be considered that the red is the result of dehydration during consolidation and that these beds retained their iron because they were deposited in an upper and better-drained portion of the basin under a climate which permitted for a time their seasonal drying.

Turning to the climatic significance of red, it would therefore appear both from theoretical considerations and geological observations that the chief condition for the formation of red shales and sandstones is merely the alternation of seasons of warmth and dryness with seasons of flood, by means of which hydration, but especially

[1] *The Basin of Eastern Persia and Sistan*, "Carnegie Institution Publications," No. 26, 1905, p. 287.

[2] "Geology of the Narragansett Basin," *Monograph XXXIII*, U. S. Geological Survey, 1899, pp. 134, 141.

oxidation of the ferruginous material in the flood-plain deposits is accomplished. This supplements the decomposition at the source and that which takes place in the long transportation and great wear to which the larger rivers subject the detritus rolled along their beds. The annual wetting, drying, and oxidation not only decompose the original iron minerals but completely remove all traces of carbon. If this conclusion be correct, red shales or sandstones, as distinct from red mud and sand, may originate under intermittently rainy, subarid, or arid climates without any close relation to temperature and typically as fluvial and pluvial deposits upon the land, though to a limited extent as fluviatile sediments coming to rest upon the bottom of the shallow sea. The origin of such sediment is most favored by climates which are hot and alternately wet and dry as opposed to climates which are either constantly cool or constantly wet or constantly dry.

The origin of light and variegated colors.—White or light gray in rocks indicates an absence of iron, an absence which may be due to entirely mechanical causes, as in white clean sandstones of either fluvial, pluvial, marine, or aeolian origin; or to chemical causes, as in gray or black clays.

Aeolian deposits whether coarse or fine, as dune sand or loess, are typically light in color, varying from nearly white to pale yellow or pink. The lightness in color appears to be due in dune sand to the mechanical segregation of the grains, but in loess partly to the lack of decomposition, partly to the lack of diffusion of the coloring substance. The preceding discussion upon the significance of red would suggest that loess deposits older than the Pleistocene should be dominantly colored from white to light pink rather than the more customary pale buff of the recent deposits. Upon weathering, however, such a buff color would tend to be to some extent restored on account of the porous nature and the new decomposition which is possible in the case of loess.

Where lightness in color is due to chemical causes it is to be noted that the first result of the action of fermenting organic matter upon ferruginous clays is a change of color from rusty to bluish or greenish by the reduction of ferric to ferroso-ferric hydrate. Afterward, if the action be continued, the solution of ferrous carbonate may be formed, and the greenish or bluish color may disappear. The impor-

tance of this reaction lies in the fact that the blue or green tint, wherever it occurs, indicates a lack of aeration, usually by the stagnation of water, in consequence of imperfect drainage.[1]

It is seen in conclusion that where the light color is due to mechanical causes the mode of origin of the formation and the climatic conditions must be determined on other grounds than color. Further, where limited development of white, gray, green, or blue occurs, owing to chemical action upon the iron, the conditions represent a variable balance between the action of iron and carbon determined by local topographic rather than climatic conditions. Where such colors are rather abundant, however, over broad areas of non-marine formations a mean, rather than an extreme, climate is indicated.

The origin of gray to black formations.—The conclusions on this topic are rather obvious from the preceding discussion on the "effects of constantly rainy climates." They need, therefore, only be summarized at this point for completness.

Where a whole formation, representing an ancient floodplain or delta, shows in its unweathered portions an absence throughout of the colors due to iron oxide, and a variable presence of carbon, giving grays to black, the inference is that the formation accumulated under a continuously rainy climate or one which in the drier season was sufficiently cool or cold to prevent noteworthy evaporation; such climates as exist in Ireland, Iceland, or western Alaska; to a minor extent on windward slopes in the trade-wind zones and also to a minor extent in a few tropical belts which never quite escape from the shifting zones of tropical rains.

CONCLUSIONS ON CLIMATIC INFLUENCES IN REGIONS OF DEPOSITION

It was seen in the discussion on the relations of climate to regions of erosion that climate was one of the controlling factors in determining the quantity, but more especially the physical and chemical nature, of the sediment supplied to the rivers. But some large river systems have their sources in climatic zones distinct from that of their lower courses. Furthermore, the comminution and decay involved in transportation and the varied contributions of tributaries obscure

[1] Hilgard, *Soils*, 1906, p. 45.

to an extent, depending upon the size of these factors, the climatic indications given by erosion. In proportion as such occur, however, the climatic influences in the region of deposition grow more pronounced, until finally over the larger deltas, where the fine-grained waste is deposited on nearly horizontal surfaces, the climatic effects become a dominant influence in the nature of sedimentation.

From the extremes of cool and rainy climates on the one hand to hot and arid on the other a gradation in character of deposits may be observed corresponding to that gradation which exists in climatic cause. For the sake of discussion, however, artificial division lines must be drawn separating the climates into several categories, as has been done. In consequence, except in clearly marked instances there may be some doubt as to the exact climatic division to which a certain deposit belongs. To reach the greatest certainty every line of evidence must be followed to its end and given appropriate weight in governing the conclusion. Only by the convergence of many probabilities may reasonable certainty be attained.

The most obvious chemical features of subaerial river deposits which depend upon the climatic gamut consist in the antithetical relations of carbon and ferric oxide. Supplemental to these two chief indicators stand the other more or less soluble substances, magnesium and calcium carbonates, hydrous calcium sulphate, sodium and potassium chlorides; wholly absent from river deposits of the one climatic extreme, appearing in successive order in deposits made under climates representing gradations toward and to the other. Supplemental to these primary chemical distinctions are the textural, structural, and organic evidences.

Varying powers of erosion and transportation giving rise to varying quality and quantity of sediment are seen to be the most delicate stratigraphic indicators of *climatic fluctuations*. On the other hand the chemical and organic conditions accompanying the deposition of the sediment upon the delta plain are the more secure indicators of the *stable and average climatic conditions* under which the formation as a whole was made.

(*To be concluded*)

Editorial

American geologists are well aware that there has been in progress for some time a movement looking toward the establishment of a mining bureau by the United States government and the transfer to this bureau of some of the functions now served by the United States Geological Survey. It is also well known that there has been no little difference of opinion, not only among geologists but among mining engineers and mine owners as to the advisability of a separate organization and as to the relationship it should sustain, if established, to the Geological Survey. It is gratifying to observe that influential opinion is crystallizing in a very natural way and along true basic lines, and that a satisfactory outcome may be anticipated. Director Smith, of the Geological Survey, entertains the view that the proper line of cleavage lies between that class of work which is fundamentally geological and which should remain with the Survey, and that class which centers about engineering and allied technologic sciences and which should be committed to a technologic organization; and he is actively urging this view. He feels however, that the term "mining" is too broad to be properly monopolized by the new bureau, but that the term "mining technology" is fitting for a bureau devoted to the non-geological phases of mining investigation, and this term is used in most of the bills before Congress. If this division of labor and this distinction in nomenclature can be established and maintained, the Geological Survey will be glad to share the field of mining investigations with another organization, and on this basis the Survey is exerting its influence in favor of the establishment of such an independent bureau. In view of the doubt as to the establishment of this bureau during the present session of Congress, Dr. Smith has given assurance, in a letter to the Secretary of the Interior, that so long as the technological investigations relative to mining continue to be intrusted to the Survey, it will be his endeavor to develop the proposed lines of cleavage rather than to conceal them, to the end that an ultimate separation may be promoted. This attitude of the Survey is greatly to be commended, not only because of its inherent wisdom, but because it gives

assurance of a gradual, if not immediate, evolution along true basic lines, with every prospect that, when the complete separation shall take place, the relationships between the geological and technological bureaus will be most intimate and cordial, and that these bureaus will each contribute effectively to the success of the other.

T. C. C.

Reviews

CRYPTOZOÖN. REPLY TO THE REVIEW OF C. W. W.

Before the genus Cryptozoön is relegated to the indiscriminate heap of concretions, as proposed by the reviewer C. W. W. in the *Journal of Geology* (Jan.–Feb., 1908, p. 85), facts like the following ought to be considered:

This form—Cryptozoön or Concretion?—is found like concretions in wide apart localities, but unlike concretions it occurs only in connection with a certain geological formation, the Beekmantown, and in this formation it is restricted to a narrow horizon, only two of the five divisions, so far as observed, containing it.

The peculiar character of its concentric bands in the spherical or spheroidal masses so marked it that for a long time it passed as a Stromatopora, and it was not until after Dr. Roeminger's careful discrimination of the genus, that it was distinguished from Stromatopora.

The minute structure is so like that of the undoubted fossil Stromatocerima, that in some cases when sections of each are placed side by side it is difficult to distinguish them.

Passing by other indications of the organic origin of the form, it should be added that the conclusions of Mather, Hall, and Dawson should have some consideration. Dawson's views were based on the study of many sections of what he came to regard as good species of Hall's genus Cryptozoön. Such facts and considerations forbid the dropping of the genus Cryptozoön.

In the matter of ova an interrogation point should have followed the figure, as it was designed as a suggestion, rather than a demonstration. Thus one making slices of Stromatocerium finds in the microscopic field distinct lacunae. In some of these exist minute spherical masses, apparently more compact than pilae. Now it may never be possible to prove that these little spheres actually are; that they may be ova, however, is not an improbable suggestion.

H. M. S.